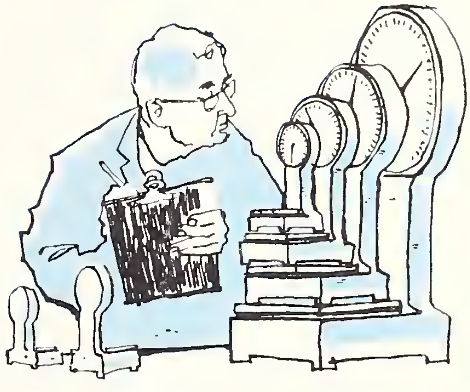
UNITED STATES DEPARTMENT OF COMMERCE
C. R. SMITH, Secretary
NATIONAL BUREAU OF STANDARDS / A. V. ASTIN, Director
Special Publication 304A. Issued 1968.

Brief History and Use of

THE ENGLISH AND METRIC SYSTEMS OF MEASUREMENT

with a
CHART OF THE MODERNIZED METRIC SYSTEM

> *"Weights and measures may be ranked among the necessaries of life to every individual of human society. They enter into the economical arrangements and daily concerns of every family. They are necessary to every occupation of human industry; to the distribution and security of every species of property; to every transaction of trade and commerce; to the labors of the husbandman; to the ingenuity of the artificer; to the studies of the philosopher; to the researches of the antiquarian, to the navigation of the mariner, and the marches of the soldier; to all the exchanges of peace, and all the operations of war."*
>
> —JOHN QUINCY ADAMS



When the American Colonies separated from the mother country to assume among the nations of the earth a separate and individual station, they retained, among other things, the weights and measures that had been used when they were colonies, namely, the weights and measures of England. It is probable that these were at that time the most firmly established and widely used weights and measures in the world.

England a highly coherent nation, separated by sea from many of the turmoils of the European continent, had long before established standards for weights and measures that have remained essentially unchanged up to the present time. The yard, established by Henry II, differs only by about 1 part in a thousand from the yard of today. The pound of Queen Elizabeth I shows similar agreement with the present avoirdupois pound.

No such uniformity of weights and measures existed on the European continent. Weights and measures differed not only from country to country, but even from town to town and from one trade to another. This lack of uniformity led the National Assembly of France on May 8, 1790, to enact a decree, sanctioned by Louis XVI, which called upon the French Academy of Sciences in concert with the Royal Society of London to "deduce an invariable standard for all of the measures and all weights." Having already an adequate system of weights and measures, the English were not interested in the French undertaking, so the French proceeded with their endeavor alone. The result is what is known as the metric system.

The metric system was conceived as a measurement system to the base ten: that is, the units of the system, their multiples, and submultiples should be related to each other by simple factors of ten. This is a great convenience because it conforms to our common system for numerical notation, which is also a base ten system. Thus to convert between units, their multiples, and submultiples, it is not necessary to perform a difficult multiplication or division process, but simply to shift the decimal point. The system seems to have been first proposed by Gabriel Mouton, a vicar of Lyons, France, in the late 17th century. He proposed to define the unit of length for the system as a fraction of the length of a great circle of the earth. This idea found favor with the French philosophers at the time of the French Revolution, men who were generally opposed to any vestige of monarchical authority and preferred a standard based on a constant of nature.

The French Academy assigned the name mètre (meter), from the Greek *metron*, a measure, to the unit of length which was supposed to be one ten millionth of the distance from the north pole to the equator, along the meridian running near Dunkirk, Paris, and Barcelona. An attempt was made to measure this meridian from northern France to southern France, from which the true distance from the pole to the equator could be calculated. The best techniques then available were used. Although the operations were carried out during a politically disturbed time, the results were in error only by about 2000 meters, a remarkable achievement in those days.

Meanwhile the National Assembly had preempted the geodetic survey, upon which the meter was to be based, and established a provisional meter. The unit of mass called the gram was

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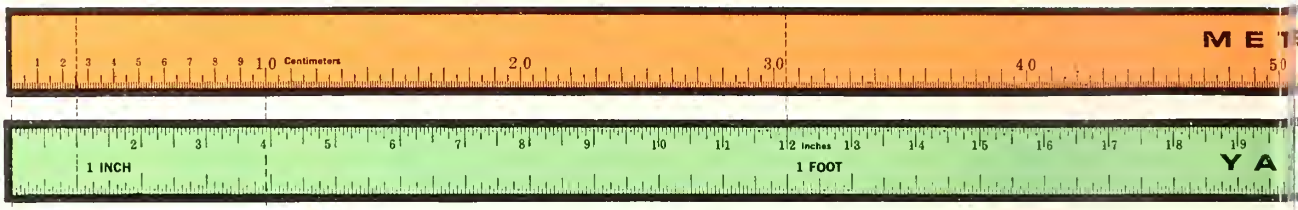
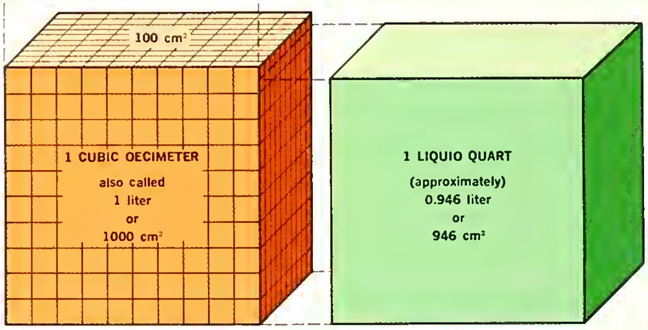
The Modernized Metric Sys





THE International System of Units—a viated SI—is a modernized version system. It was established by inter ment to provide a logical and interconnec for all measurements in science, industry, SI is built upon a foundation of base units nitions, which appear on this chart. All ot

The Six Base Units of Measurem

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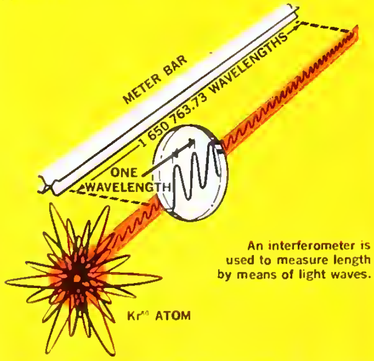

An interferometer is used to measure length by means of light waves.

The SI unit of area is the square meter (m^2). Land is often measured by the hectare (10 000 square meters, or approximately 2.5 acres).

The SI unit of volume is the cubic meter (m^3). Fluid volume is often measured by the liter (0.001 cubic meter).

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References:
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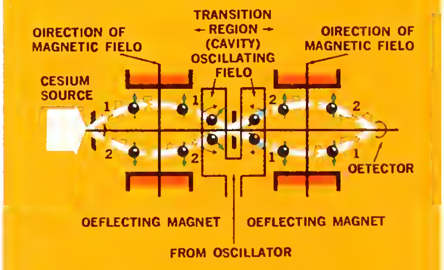
NBS Misc. Publ. 286, Units of Weight and Measure, Definitions and Tables of Equivalents, $1.50

Time SECOND-s

The second is defined as the duration of 9 192 631 770 cycles of the radiation associated with a specified transition of the cesium atom. It is realized by tuning an oscillator to the resonance frequency of the cesium atoms as they pass through a system of magnets and a resonant cavity into a detector.



A schematic of an atomic beam spectrometer. The trajectories are drawn for those atoms whose magnetic moments are "flipped" in the transition region.

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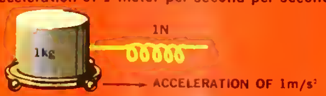
Mass KILOGRAM–kg

The standard for the unit of mass, the kilogram, is a cylinder of platinum-iridium alloy kept by the International Bureau of Weights and Measures at Paris. A duplicate in the custody of the National Bureau of Standards serves as the mass standard for the United States. This is the only base unit still defined by an artifact.

Closely allied to the concept of mass is that of force. The SI unit of force is the newton (N). A force of 1 newton, when applied for 1 second, will give to a 1 kilogram mass a speed of 1 meter per second (an acceleration of 1 meter per second per second).



$$1N = \frac{1kg \cdot 1m}{1s^2}$$

One newton equals approximately two tenths of a pound of force.

The weight of an object is the force exerted on it by gravity. Gravity gives a mass a downward acceleration of about $9.8 m/s^2$.

The SI unit for work and energy of any kind is the joule (J).

$$1J = 1N \cdot 1m$$

The SI unit for power of any kind is the watt (W).

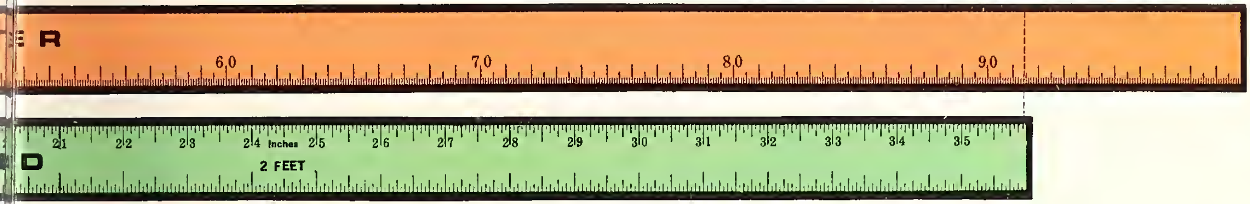
$$1W = \frac{1J}{1s}$$

This chart is one-third the actual size of the full-scale wall chart, NBS Special Publication 304, which is availabl

tem

The International System of Units (SI) and its relationship to U.S. customary units

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards



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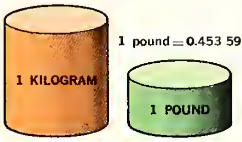
The kilogram shown here approximates one third the size of the platinum-iridium standard of mass. One pound of the same material would be three times the size shown below.



1 pound = 0.453 592 37 kg

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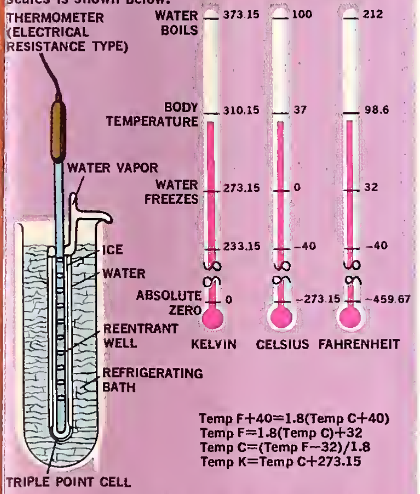
definitions, abbreviations,
and some SI units derived from them

Temperature KELVIN--K

The thermodynamic or Kelvin scale of temperature used in SI has its origin or zero point at absolute zero and has a fixed point at the triple point of water defined as 273.16 kelvins. The Celsius scale is derived from the Kelvin scale. The triple point is defined as 0.01 °C on the Celsius scale, which is approximately 32.02 °F on the Fahrenheit scale. The relationship of the Kelvin, Celsius, and Fahrenheit temperature scales is shown below.

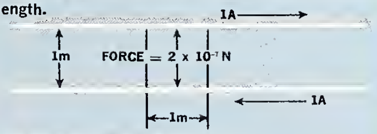


Temp F+40=1.8(Temp C+40)
Temp F=1.8(Temp C)+32
Temp C=(Temp F−32)/1.8
Temp K=Temp C+273.15

The triple point cell, an evacuated glass cylinder filled with pure water, is used to define a known fixed temperature. When the cell is cooled until a mantle of ice forms around the reentrant well, the temperature at the interface of solid, liquid, and vapor is 0.01 °C. Thermometers to be calibrated are placed in the reentrant well.

Electric Current AMPERE—A

The ampere is defined as the magnitude of the current that, when flowing through each of two long parallel wires separated by one meter in free space, results in a force between the two wires (due to their magnetic fields) of 2×10^{-7} newton for each meter of length.



The SI unit of voltage is the volt (V).

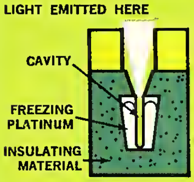
$$1V = \frac{1W}{1A}$$

The SI unit of electrical resistance is the ohm (Ω).

$$1\ \Omega = \frac{1V}{1A}$$

Luminous Intensity CANDELA—cd

The candela is defined as the luminous intensity of 1/600 000 of a square meter of a radiating cavity at the temperature of freezing platinum (2042 K).



The SI unit of light flux is the lumen (lm). A source having an intensity of 1 candela in all directions radiates a light flux of 4π lumens.

A 100-watt light bulb emits about 1700 lumens

COMMON EQUIVALENTS AND CONVERSIONS

Approximate Common Equivalents	
1 inch	=25 millimeters
1 foot	=0.3 meter
1 yard	=0.9 meter
1 mile	=1.6 kilometers
1 square inch	=6.5 sq centimeters
1 square foot	=0.09 square meter
1 square yard	=0.8 square meter
1 acre	=0.4 hectare †
1 cubic inch	=16 cu centimeters
1 cubic foot	=0.03 cubic meter
1 cubic yard	=0.8 cubic meter
1 quart (lq)	=1 liter †
1 gallon	=0.004 cubic meter
1 ounce (avdp)	=28 grams
1 pound (avdp)	=0.45 kilogram
1 horsepower	=0.75 kilowatt
1 millimeter	=0.04 inch
1 meter	=3.3 feet
1 meter	=1.1 yards
1 kilometer	=0.6 mile
1 sq centimeter	=0.16 square inch
1 square meter	=11 square feet
1 square meter	=1.2 square yards
1 hectare †	=2.5 acres
1 cu centimeter	=0.06 cubic inch
1 cubic meter	=35 cubic feet
1 cubic meter	=1.3 cubic yards
1 liter †	=1 quart (lq)
1 cubic meter	=250 gallons
1 gram	=0.035 ounces (avdp)
1 kilogram	=2.2 pounds (avdp)
1 kilowatt	=1.3 horsepower

† common term not used in SI

Conversions Accurate to Parts Per Million	
inches x 25.4*	=millimeters
feet x 0.3048*	=meters
yards x 0.9144*	=meters
miles x 1.609 34	=kilometers
square inches x 6.4516*	=sq centimeters
square feet x 0.092 903 0	=square meters
square yards x 0.836 127	=square meters
acres x 0.404 686	=hectares
cubic inches x 16.3871	=cu centimeters
cubic feet x 0.028 316 8	=cubic meters
cubic yards x 0.764 555	=cubic meters
quarts (lq) x 0.946 353	=liters
gallons x 0.003 785 41	=cubic meters
ounces (avdp) x 28.349 5	=grams
pounds (avdp) x 0.453 592	=kilograms
horsepower x 0.745 700	=kilowatts
millimeters x 0.039 370 1	=inches
meters x 3.280 84	=feet
meters x 1.093 61	=yards
kilometers x 0.621 371	=miles
sq centimeters x 0.155 000	=square inches
square meters x 10.7639	=square feet
square meters x 1.195 99	=square yards
hectares x 2.471 05	=acres
cu centimeters x 0.061 023 7	=cubic inches
cubic meters x 35.3147	=cubic feet
cubic meters x 1.307 95	=cubic yards
liters x 1.056 69	=quarts (lq)
cubic meters x 264.172	=gallons
grams x 0.035 274 0	=ounces (avdp)
kilograms x 2.204 62	=pounds (avdp)
kilowatts x 1.341 02	=horsepower

* exact

THESE PREFIXES MAY BE APPLIED TO ALL SI UNITS

Multiples and Submultiples	Prefixes	Symbols
1 000 000 000 000 = 10^{12}	tera (tĕr′ȧ)	T
1 000 000 000 = 10^{9}	giga (jĭ′gȧ)	G
1 000 000 = 10^{6}	mega (mĕg′ȧ)	M *
1000 = 10^{3}	kilo (kĭl′ō)	k *
100 = 10^{2}	hecto (hĕk′tō)	h
10 = 10	deka (dĕk′ȧ)	da
0.1 = 10^{-1}	deci (dĕs′ĭ)	d
0.01 = 10^{-2}	centi (sĕn′tĭ)	c *
0.001 = 10^{-3}	milli (mĭl′ĭ)	m *
0.000 001 = 10^{-6}	micro (mī′krō)	μ *
0.000 000 001 = 10^{-9}	nano (năn′ō)	n
0.000 000 000 001 = 10^{-12}	pico (pē′kō)	p
0.000 000 000 000 001 = 10^{-15}	femto (fĕm′tō)	f
0.000 000 000 000 000 001 = 10^{-18}	atto (ăt′tō)	a

*Most commonly used

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The Modernized Metric System

The International System of Units (SI) and its relationship to U.S. customary units

U.S. DEPARTMENT OF COMMERCE
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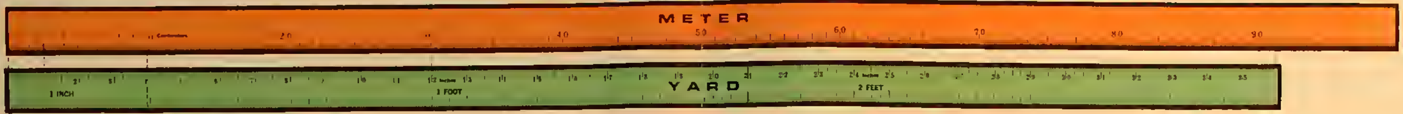

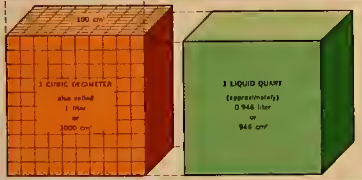

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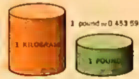

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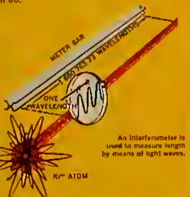

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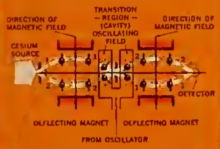

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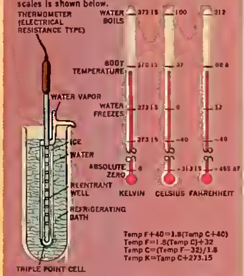

Temp F+40=1.8(Temp C+40)
Temp F=1.8(Temp C)+32
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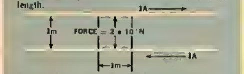
Temp K=Temp C+273.15

The triple point cell, an evacuated glass cylinder filled with pure water, is used to define a known fixed temperature. When the cell is cooled until a mantle of ice forms around the reentrant well, the temperature at the interface of solid, liquid, and vapor is 0.01 °C. Thermometers to be calibrated are placed in the reentrant well.

Electric Current AMPERE–A

The ampere is defined as the magnitude of the current that, when flowing through each of two long parallel wires separated by one meter in free space, results in a force between the two wires (due to their magnetic fields) of 2×10^{-7} newton for each meter of length.



The SI unit of voltage is the volt (V).

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The SI unit of electrical resistance is the ohm (Ω).

$$1\,\Omega = \frac{1V}{1A}$$

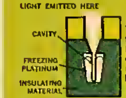
COMMON EQUIVALENTS AND CONVERSIONS

Approximate Common Equivalents		Conversions Accurate to Parts Per Million	
1 inch	= 25 millimeters	inches × 25.4*	= millimeters
1 foot	= 0.3 meter	feet × 0.3048*	= meters
1 yard	= 0.9 meter	yards × 0.9144*	= meters
1 mile	= 1.6 kilometers	miles × 1.609 34	= kilometers
1 square inch	= 6.5 sq centimeters	square inches × 6.4516*	= sq centimeters
1 square foot	= 0.09 square meter	square feet × 0.092 903 0	= square meters
1 square yard	= 0.8 square meter	square yards × 0.836 127	= square meters
1 acre	= 0.4 hectare	acres × 0.404 686	= hectares
1 cubic inch	= 16 cu centimeters	cubic inches × 16.3871	= cu centimeters
1 cubic foot	= 0.03 cubic meter	cubic feet × 0.028 316 8	= cubic meters
1 cubic yard	= 0.8 cubic meter	cubic yards × 0.764 555	= cubic meters
1 quart (lq)	= 1 liter	quarts (lq) × 0.946 353	= liters
1 gallon	= 0.004 cubic meter	gallons × 0.003 785 41	= cubic meters
1 ounce (avdp)	= 28 grams	ounces (avdp) × 28.349 5	= grams
1 pound (avdp)	= 0.45 kilogram	pounds (avdp) × 0.453 592	= kilograms
1 horsepower	= 0.75 kilowatt	horsepower × 0.745 700	= kilowatts
1 millimeter	= 0.04 inch	millimeters × 0.039 370 1	= inches
1 meter	= 3.3 feet	meters × 3.280 84	= feet
1 meter	= 1.1 yards	meters × 1.093 61	= yards
1 kilometer	= 0.6 mile	kilometers × 0.621 371	= miles
1 sq centimeter	= 0.16 square inch	sq centimeters × 0.155 000	= square inches
1 square meter	= 11 square feet	square meters × 10.7639	= square feet
1 square meter	= 1.2 square yards	square meters × 1.195 99	= square yards
1 hectare	= 2.5 acres	hectares × 2.471 05	= acres
1 cu centimeter	= 0.06 cubic inch	cu centimeters × 0.061 023 7	= cubic inches
1 cubic meter	= 35 cubic feet	cubic meters × 35.3147	= cubic feet
1 cubic meter	= 1.3 cubic yards	cubic meters × 1.307 95	= cubic yards
1 liter	= 1 quart (lq)	liters × 1.056 69	= quarts (lq)
1 cubic meter	= 250 gallons	cubic meters × 264.172	= gallons
1 gram	= 0.035 ounce (avdp)	grams × 0.035 274 0	= ounces (avdp)
1 kilogram	= 2.2 pounds (avdp)	kilograms × 2.204 62	= pounds (avdp)
1 kilowatt	= 1.3 horsepower	kilowatts × 1.341 02	= horsepower

† common term not used in SI
* exact

Luminous Intensity CANDELA–cd

The candela is defined as the luminous intensity of 1/600 000 of a square meter of a radiating cavity at the temperature of freezing platinum (2042 K).



The SI unit of light flux is the lumen (lm). A source having an intensity of 1 candela in all directions radiates a light flux of 4π lumens.

A 100-watt light bulb emits about 1700 lumens

THESE PREFIXES MAY BE APPLIED TO ALL SI UNITS

Multiples and Submultiples	Prefixes	Symbols
1 000 000 000 000 = 10^{12}	tera (ter'a)	T
1 000 000 000 = 10^{9}	giga (ji'ga)	G
1 000 000 = 10^{6}	mega (meg'a)	M*
1000 = 10^{3}	kilo (kil'ō)	k*
100 = 10^{2}	hecto (hek'tō)	h
10 = 10	deka (dek'a)	da
0.1 = 10^{-1}	deci (des'i)	d
0.01 = 10^{-2}	centi (sen'ti)	c*
0.001 = 10^{-3}	milli (mil'i)	m*
0.000 001 = 10^{-6}	micro (mī'krō)	μ*
0.000 000 001 = 10^{-9}	nano (nan'ō)	n
0.000 000 000 001 = 10^{-12}	pico (pē'kō)	p
0.000 000 000 000 001 = 10^{-15}	femto (fem'tō)	f
0.000 000 000 000 000 001 = 10^{-18}	atto (at'tō)	a

*Most commonly used

This chart is one-third the actual size of the full-scale wall chart, NBS Special Publication 304, which is available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, for 50 cents.

decided on as the mass of one cubic centimeter of water at its temperature of maximum density. Since this was too small a quantity to be measured with the desired precision the determination was made on one cubic decimeter of water, but even at that the results were found to be in error by about 28 parts in a million. Thus, the meter that was established as the foundation of the system did not approximate the idealized definition on which it was based with the desired accuracy. Also the unit of mass differed from the idealized definition even as given in terms of the erroneously defined meter. So the new system was actually based on two metallic standards not differing greatly in nature from the yard of Henry II or the pound of Elizabeth I.

As a unit for fluid capacity, the founders selected the cubic decimeter and as a unit for land area they selected the are, equal to a square ten meters on the side. In this manner, while decimal relationships were preserved between the units of length, fluid capacity, and area, the relationships were not kept to the simplest possible form. Although there was some discussion at the time of decimalizing the calendar and the time of day, the system did not include any unit for time.

The British system of weights and measures, and the metric system as well, had been developed primarily for use in trade and commerce rather than for purposes of science and engineering.

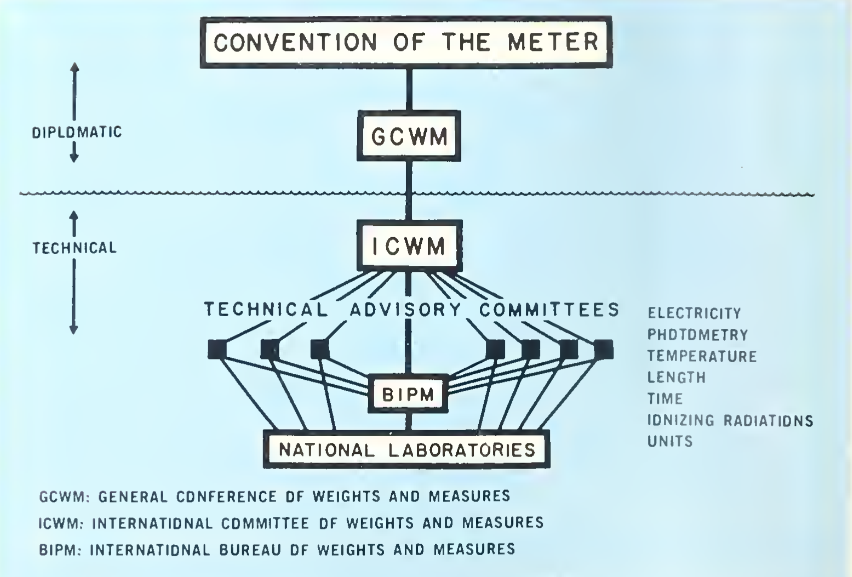
Because technological achievement depends to a considerable extent upon the ability to make physical measurements, the Americans and the British proceeded to adapt their system of measurements to the requirements of the new technology of the 19th century, despite the fact that the newly developed metric system seemed to have certain points of superiority. Both the United States and Great Britain soon had vast investments in a highly industrialized society based on their own system.

The new metric system found much favor with scientists of the 19th century, partly because it was intended to be an international system of measurement, partly because the units of measurement were theoretically supposed to be independently reproducible, and partly because of the simplicity of its decimal nature. These scientists proceeded to derive new units for the various physical quantities with which they had to deal, basing the new units on elementary laws of physics and relating them to the units of mass and length of the metric system. The system found increasing acceptance in various European countries which had been plagued by a plethora of unrelated units for different quantities.

Because of increasing technological development there was a need for international standardization and improvements in the accuracy of standards for units of length and mass. This led to an international meeting in France in 1872, attended by 26 countries including the United States. The meeting resulted in an international treaty, the Metric Convention, which was signed by 17 countries, including the United States in 1875. This treaty set up well defined metric standards for length and mass, and established the International Bureau of Weights and Measures. Also established was the General Conference of Weights and Measures, which would meet every six years to consider any needed improvements in the standards and to serve as the authority governing the International Bureau. An International Committee of Weights and Measures was also set up to implement the recommendations of the General Conference and to direct the activities of the International Bureau; this Committee meets every two years.

Since its inception nearly 175 years ago, the number of countries using the metric system has been growing rapidly. The original metric system of course had imperfections; and it has since undergone many revisions, the more recent ones being accomplished through the General Conference of Weights and Measures. An extensive revision and simplification in 1960 by the then 40 members of the General Conference resulted in a modernized metric system—the International System of Units—which is described in detail in the accompanying chart.

NOTE: For further information see the references listed on the chart. In addition, a more complete treatment of the English and metric systems of measurement will soon be available.



GCWM: GENERAL CONFERENCE OF WEIGHTS AND MEASURES
ICWM: INTERNATIONAL COMMITTEE OF WEIGHTS AND MEASURES
BIPM: INTERNATIONAL BUREAU OF WEIGHTS AND MEASURES

INTERNATIONAL COORDINATION OF MEASUREMENT STANDARDS

U. S. GOVERNMENT PRINTING OFFICE : 1969 O - 325-509

UNITED STATES DEPARTMENT OF COMMERCE
FREDERICK B. DENT, Secretary
NATIONAL BUREAU OF STANDARDS / RICHARD W. ROBERTS, Director

Special Publication 304 A. Reissued September, 1974

Brief History of MEASUREMENT SYSTEMS

with a Chart of the Modernized Metric System

> *"Weights and measures may be ranked among the necessaries of life to every individual of human society. They enter into the economical arrangements and daily concerns of every family. They are necessary to every occupation of human industry; to the distribution and security of every species of property; to every transaction of trade and commerce; to the labors of the husbandman; to the ingenuity of the artificer; to the studies of the philosopher; to the researches of the antiquarian, to the navigation of the mariner, and the marches of the soldier; to all the exchanges of peace, and all the operations of war. The knowledge of them, as in established use, is among the first elements of education, and is often learned by those who learn nothing else, not even to read and write. This knowledge is riveted in the memory by the habitual application of it to the employments of men throughout life."*
>
> JOHN QUINCY ADAMS
> Report to the Congress, 1821

Weights and measures were among the earliest tools invented by man. Primitive societies needed rudimentary measures for many tasks: constructing dwellings of an appropriate size and shape, fashioning clothing, or bartering food or raw materials.

Man understandably turned first to parts of his body and his natural surroundings for measuring instruments. Early Babylonian and Egyptian records and the Bible indicate that length was first measured with the forearm, hand, or finger and that time was measured by the periods of the sun, moon, and other heavenly bodies. When it was necessary to compare the capacities of containers such as gourds or clay or metal vessels, they were filled with plant seeds which were then counted to measure the volumes. When means for weighing were invented, seeds and stones served as standards. For instance, the "carat," still used as a unit for gems, was derived from the carob seed.

As societies evolved, weights and measures became more complex. The invention of numbering systems and the science of mathematics made it possible to create whole systems of weights and measures suited to trade and commerce, land division, taxation, or scientific research. For these more sophisticated uses it was necessary not only to weigh and measure more complex things—it was also necessary to do it accurately time after time and in different places. However, with limited international exchange of goods and communication of ideas, it is not surprising that different systems for the same purpose developed and became established in different parts of the world—even in different parts of a single continent.

The English System

The measurement system commonly used in the United States today is nearly the same as that brought by the colonists from England. These measures had their origins in a variety of cultures—Babylonian, Egyptian, Roman, Anglo-Saxon, and Norman French. The ancient "digit," "palm," "span," and "cubit" units evolved into the "inch," "foot," and "yard" through a complicated transformation not yet fully understood.

Roman contributions include the use of the number 12 as a base (our foot is divided into 12 inches) and words from which we derive many of our present weights and measures names. For example, the 12 divisions of the Roman "pes," or foot, were called *unciae*. Our words "inch" and "ounce" are both derived from that Latin word.

The "yard" as a measure of length can be traced back to the early Saxon kings. They wore a sash or girdle around the waist—that could be removed and used as a convenient measuring device. Thus the word "yard" comes from the Saxon word "gird" meaning the circumference of a person's waist.

Standardization of the various units and their combinations into a loosely related system of weights and measures sometimes occurred in fascinating ways. Tradition holds that King Henry I decreed that the yard should be the distance from the tip of his nose to the end of his thumb. The length of a furlong (or furrow-long) was established by early Tudor rulers as 220 yards. This led Queen Elizabeth I to declare, in the 16th century, that henceforth the traditional Roman mile of 5,000 feet would be replaced by one of 5,280 feet, making the mile exactly 8 furlongs and providing a convenient relationship between two previously ill-related measures.

Thus, through royal edicts, England by the 18th century had achieved a greater degree of standardization than the continental countries. The English units were well suited to commerce and trade because they had been developed and refined to meet commercial needs. Through colonization and dominance of world commerce during the 17th, 18th,

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THE MODERNIZED metric system

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COMMON CONVERSIONS
Accurate to Six Significant Figures

Symbol	When You Know	Multiply by	To Find	Symbol
in	inches	[A]25.4	[B]millimeters	mm
ft	feet	[A]0.3048	meters	m
yd	yards	[A]0.9144	meters	m
mi	miles	1.609 34	kilometers	km
yd^2	square yards	0.836 127	square meters	m^2
	acres	0.404 686	[C]hectares	ha
yd^3	cubic yards	0.764 555	cubic meters	m^3
qt	quarts (lq)	0.946 353	[D]liters	l
oz	ounces (avdp)	28.349 5	grams	g
lb	pounds (avdp)	0.453 592	kilograms	kg
°F	Fahrenheit temperature	[A]5/9 (after subtracting 32)	Celsius temperature	°C
mm	millimeters	0.039 370 1	inches	in
m	meters	3.280 84	feet	ft
m	meters	1.093 61	yards	yd
km	kilometers	0.621 371	miles	mi
m^2	square meters	1.195 99	square yards	yd^2
ha	[C]hectares	2.471 05	acres	
m^3	cubic meters	1.307 95	cubic yards	yd^3
l	[D]liters	1.056 69	quarts (lq)	qt
g	grams	0.035 274 0	ounces (avdp)	oz
kg	kilograms	2.204 62	pounds (avdp)	lb
°C	Celsius temperature	[A]9/5 (then add 32)	Fahrenheit temperature	°F

[A] exact

[a] for example, 1 in = 25.4 mm, so 3 inches would be $(3\ \text{in})\left(25.4\ \frac{\text{mm}}{\text{in}}\right) = 76.2\ \text{mm}$

[C] hectare is a common name for 10 000 square meters

[D] liter is a common name for fluid volume of 0.001 cubic meter

Note: Most symbols are written with lower case letters; exceptions are units named after persons for which the symbols are capitalized. Periods are not used with any symbols.

MULTIPLES AND PREFIXES
These Prefixes May Be Applied To All SI Units

Multiples and Submultiples		Prefixes	Symbols
1 000 000 000 000	10^{12}	tera (tĕr′ȧ)	T
1 000 000 000	10^{9}	giga (jĭ′gȧ)	G
1 000 000	10^{6}	mega (mĕg′ȧ)	M
1 000	10^{3}	kilo (kĭl′ō)	k
100	10^{2}	hecto (hĕk′tō)	h
10	10^{1}	deka (dĕk′ȧ)	da
Base Unit 1	10^{0}		
0.1	10^{-1}	deci (dĕs′ĭ)	d
0.01	10^{-2}	centi (sĕn′tĭ)	c
0.001	10^{-3}	milli (mĭl′ĭ)	m
0.000 001	10^{-6}	micro (mī′krō)	μ
0.000 000 001	10^{-9}	nano (năn′ō)	n
0.000 000 000 001	10^{-12}	pico (pē′kō)	p
0.000 000 000 000 001	10^{-15}	femto (fĕm′tō)	f
0.000 000 000 000 000 001	10^{-18}	atto (ăt′tō)	a

National Bureau of Standards
Special Publication 304A (Revised October 1972)
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SD Catalog No. C13.10: 304A — Price 25 cents

REFERENCES

NBS Special Publication 330, 1972 Edition, International System of Units (SI), available by purchase from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402, order as C13.10:330/2; 30 cents a copy.

ASTM Metric Practice Guide E380-72, available by purchase from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103, $1.50 a copy, minimum order $3.00.

SI Units and Recommendations for the Use of Their Multiples and of Certain Other Units, order as ISO Standard 1000, $1.50 a copy, from the American National Standards Institute, 1430 Broadway, N.Y., N.Y. 10018.

meter-m
LENGTH

The meter (rom
is defined as 6
the orange-red l

kilogram-kg
MASS

The
cyli
tion
plic
ards
This

second-s
TIME

The second is de
cycles of the ra
transition of the
tuning an oscill
cesium-133 aton
magnets and a r

Schematic diagram of
magnetic moments a
9 192 631 770 oscilla

ampere-A
ELECTRIC CURRENT

kelvin-K
TEMPERATURE

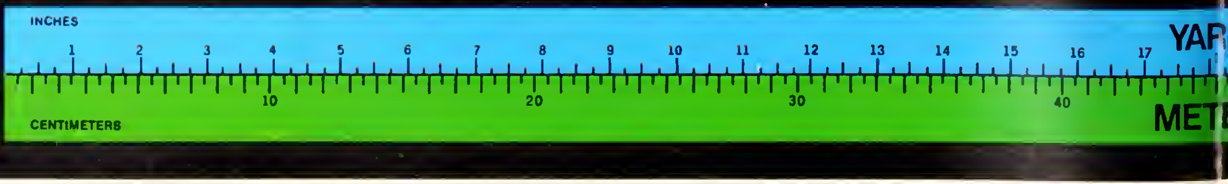
The kelvin is def
tion 1/273.16 of
namic temperatu
point of water. T
0 K is called "ab

mole-mol
AMOUNT OF SUBSTANC

candela-cd
LUMINOUS INTENSITY

radian-rad
PLANE ANGLE

The radian is the
vertex at the cen
subtended by an
the radius.

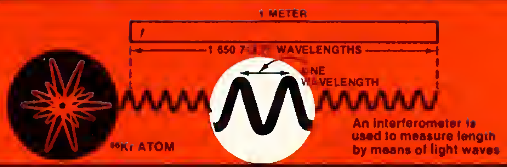


A full-scale wall chart, NBS Special Publication 304 (Revised October 1972,) is available from the Su

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

SEVEN BASE UNITS

rnational spelling, metre)
wavelengths in vacuum of
spectrum of krypton-86.



The SI unit of area is the **square meter** (m^2).

The SI unit of volume is the **cubic meter** (m^3). The liter (0.001 cubic meter), although not an SI unit, is commonly used to measure fluid volume.

d for the unit of mass, the kilogram, is a
platinum-iridium alloy kept by the Interna-
u of Weights and Measures at Paris. A du-
e custody of the National Bureau of Stand-
as the mass standard for the United States.
nly base unit still defined by an artifact.

The SI unit of force is the **newton** (N). One newton is the force which, when applied to a 1 kilogram mass, will give the kilogram mass an acceleration of 1 (meter per second) per second.

$1N = 1kg{\cdot}m/s^2$

The SI unit for pressure is the **pascal** (Pa).

$1Pa = 1N/m^2$

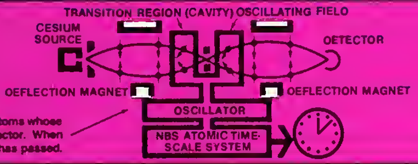
The SI unit for work and energy of any kind is the **joule** (J).

$1J = 1N{\cdot}m$

The SI unit for power of any kind is the **watt** (W).

$1W = 1J/s$

the duration of 9 192 631 770
associated with a specified
-133 atom. It is realized by
he resonance frequency of
y pass through a system of
cavity into a detector



beam spectrometer or "clock." Only those atoms whose
" in the transition region reach the detector. When
occurred, the clock indicates one second has passed.

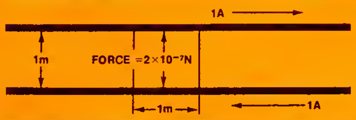
The number of periods or cycles per second is called frequency. The SI unit for frequency is the **hertz** (Hz). One hertz equals one cycle per second.

The SI unit for speed is the **meter per second** (m/s).

The SI unit for acceleration is the **(meter per second) per second** (m/s^2).

Standard frequencies and correct time are broadcast from WWV, WWVB, and WWVH, and stations of the U.S. Navy. Many short-wave receivers pick up WWV and WWVH, on frequencies of 2.5, 5, 10, 15, and 20 megahertz.

pere is defined as that current which, if maintained in each of two
rallel wires separated by one meter in free space, would produce
between the two wires (due to their magnetic fields) of 2 × 10^{-7}
for each meter of length.



The SI unit of voltage is the **volt** (V).

$1V = 1W/A$

The SI unit of electric resistance is the **ohm** (Ω).

$1\Omega = 1V/A$

he frac-
ermody-
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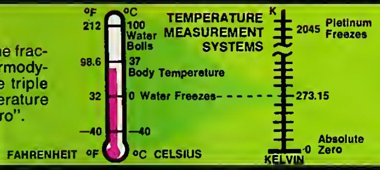
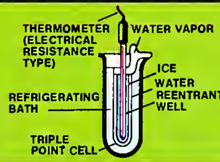


On the commonly used Celsius temperature scale, water freezes at about 0 °C and boils at about 100 °C. The °C is defined as an interval of 1 K, and the Celsius temperature 0 °C is defined as 273.15 K.

1.8 Fahrenheit degrees are equal to 1.0 °C or 1.0 K; the Fahrenheit scale uses 32 °F as a temperature corresponding to 0 °C.



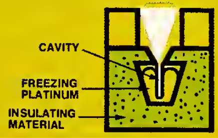
The standard temperature at the triple point of water is provided by a special cell, an evacuated glass cylinder containing pure water. When the cell is cooled until a mantle of ice forms around the reentrant well, the temperature at the interface of solid, liquid, and vapor is 273.16 K. Thermometers to be calibrated are placed in the reentrant well.

The mole is the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.

When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

The SI unit of concentration (of amount of substance) is the **mole per cubic meter** (mol/m^3).

The candela is defined as the luminous intensity of 1/600 000 of a square meter of a blackbody at the temperature of freezing platinum (2045 K).



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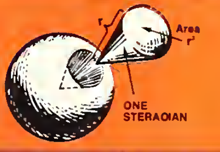
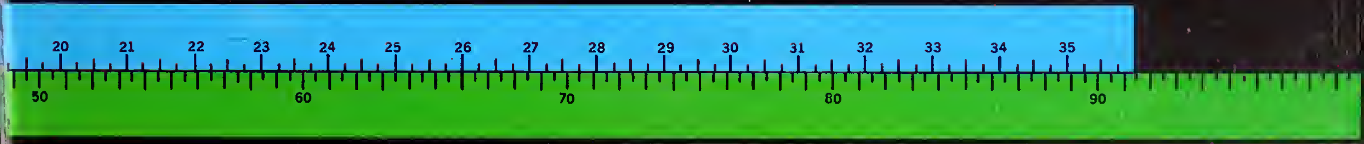
TWO SUPPLEMENTARY UNITS

angle with its
circle that is
al in length to

steradian-sr
SOLID ANGLE

The steradian is the solid angle with its vertex at the center of a sphere that is subtended by an area of the spherical surface equal to that of a square with sides equal in length to the radius.





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g	grams	0.035 274 0	ounces (avdp)	oz
kg	kilograms	2.204 62	pounds (avdp)	lb
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*exact

†for example, 1 in = 25.4 mm, so 3 inches would be (3 in)(25.4 $\frac{mm}{in}$) = 76.2 mm

‡hectare is a common name for 10 000 square meters

§liter is a common name for fluid volume of 0.001 cubic meter

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1 000 000	10^{6}	mega (mĕg′ȧ)	M
1 000	10^{3}	kilo (kĭl′ō)	k
100	10^{2}	hecto (hĕk′tō)	h
10	10^{1}	deka (dĕk′ȧ)	da
Base Unit 1	10^{0}		
0.1	10^{-1}	deci (dĕs′ĭ)	d
0.01	10^{-2}	centi (sĕn′tĭ)	c
0.001	10^{-3}	milli (mĭl′ĭ)	m
0.000 001	10^{-6}	micro (mī′krō)	µ
0.000 000 001	10^{-9}	nano (năn′ō)	n
0.000 000 000 001	10^{-12}	pico (pē′kō)	p
0.000 000 000 000 001	10^{-15}	femto (fĕm′tō)	f
0.000 000 000 000 000 001	10^{-18}	atto (ăt′tō)	a

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U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

SEVEN BASE UNITS

meter-m
LENGTH

[illegible] krypton 86 [illegible]


An interferometer is used to measure length by means of light waves.

The SI unit of area is the square meter (m²).

The SI unit of volume is the cubic meter (m³). [illegible]

kilogram-kg
MASS

The standard for the unit of mass, the kilogram, is a cylinder of platinum-iridium alloy kept by the International Bureau of Weights and Measures at Paris. A duplicate in the custody of the National Bureau of Standards serves as the mass standard for the United States. This is the only base unit still defined by an artifact.

The SI unit of force is the newton (N). One newton is the force which, when applied to a 1 kilogram mass, will give the kilogram mass an acceleration of 1 (meter per second) per second.
1N = 1kg·m/s²

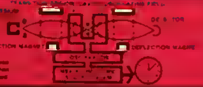
The SI unit for pressure is the pascal (Pa).
1Pa = 1N/m²

The SI unit for work and energy of any kind is the joule (J).
1J = 1N·m

The SI unit for power of any kind is the watt (W).
1W = 1J/s

second-s
TIME

[illegible]



Schematic diagram of an atomic beam spectrometer or "clock." Only those atoms whose magnetic moments are "flipped" in the transition region reach the detector. When 9 192 631 770 oscillations have occurred, the clock indicates one second has passed.

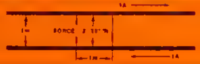
[illegible] hertz [illegible]

The [illegible] meter per second [illegible] (meter per second) per second.

[illegible]

ampere-A
ELECTRIC CURRENT

The ampere is defined as that current which, if maintained in each of two long parallel wires separated by one meter in free space, would produce a force between the two wires (due to their magnetic fields) of 2 × 10⁻⁷ newton for each meter of length.

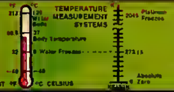


The SI unit of voltage is the volt (V).
1V = 1W/A

The SI unit of electric resistance is the ohm (Ω).
1Ω = 1V/A

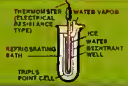
kelvin-K
TEMPERATURE

The kelvin is defined as the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. The temperature 0 K is called "absolute zero."



On the commonly used Celsius temperature scale, water freezes at about 0 °C and boils at about 100 °C. The °C is defined as an interval of 1 K, and the Celsius temperature 0 °C is defined as 273.15 K.

1.8 Fahrenheit degrees are equal to 1.0 °C or 1.0 K; the Fahrenheit scale uses 32 °F as a temperature corresponding to 0 °C.



The standard temperature at the triple point of water is provided by a special cell, an evacuated glass cylinder containing pure water. When the cell is cooled until a mantle of ice forms around the reentrant well, the temperature at the interface of solid, liquid, and vapor is 273.16 K. Thermometers to be calibrated are placed in the reentrant well.

mole-mol
AMOUNT OF SUBSTANCE

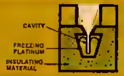
The mole is the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.

When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

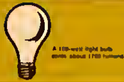
The SI unit of concentration (of amount of substance) is the mole per cubic meter (mol/m³).

candela-cd
LUMINOUS INTENSITY

The candela is defined as the luminous intensity of 1/600 000 of a square meter of a blackbody at the temperature of freezing platinum (2045 K).



The SI unit of light flux is the lumen (lm). A source having an intensity of 1 candela in all directions radiates a light flux of 4 π lumens.


A 100-watt light bulb emits about 1700 lumens.

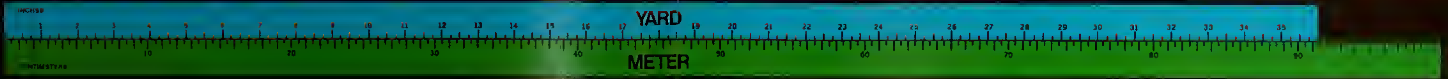
TWO SUPPLEMENTARY UNITS

radian-rad
PLANE ANGLE

The radian is the plane angle with its vertex at the center of a circle that is subtended by an arc equal in length to the radius.

steradian-sr
SOLID ANGLE

The steradian is the solid angle with its vertex at the center of a sphere that is subtended by an area of the spherical surface equal to that of a square with sides equal in length to the radius.



A full-scale wall chart, NBS Special Publication 304 (Revised October 1972), is available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

and 19th centuries, the English system of weights and measures was spread to and established in many parts of the world, including the American colonies.

However, standards still differed to an extent undesirable for commerce among the 13 colonies. The need for greater uniformity led to clauses in the Articles of Confederation (ratified by the original colonies in 1781) and the Constitution of the United States (ratified in 1790) giving power to the Congress to fix uniform standards for weights and measures. Today, standards supplied to all the States by the National Bureau of Standards assure uniformity throughout the country.

The Metric System

The need for a single worldwide coordinated measurement system was recognized over 300 years ago. Gabriel Mouton, Vicar of St. Paul in Lyons, proposed in 1670 a comprehensive decimal measurement system based on the length of one minute of arc of a great circle of the earth. In 1671 Jean Picard, a French astronomer, proposed the length of a pendulum beating seconds as the unit of length. (Such a pendulum would have been fairly easily reproducible, thus facilitating the widespread distribution of uniform standards.) Other proposals were made, but over a century elapsed before any action was taken.

In 1790, in the midst of the French Revolution, the National Assembly of France requested the French Academy of Sciences to "deduce an invariable standard for all the measures and all the weights." The Commission appointed by the Academy created a system that was, at once, simple and scientific. The unit of length was to be a portion of the earth's circumference. Measures for capacity (volume) and mass (weight) were to be derived from the unit of length, thus relating the basic units of the system to each other and to nature. Furthermore, the larger and smaller versions of each unit were to be created by multiplying or dividing the basic units by 10 and its multiples. This feature provided a great convenience to users of the system, by eliminating the need for such calculations as dividing by 16 (to convert ounces to pounds) or by 12 (to convert inches to feet). Similar calculations in the metric system could be performed simply by shifting the decimal point. Thus the metric system is a "base-10" or "decimal" system.

The Commission assigned the name *metre* (which we also spell meter) to the unit of length. This name was derived from the Greek word *metron*, meaning "a measure." The physical standard representing the meter was to be constructed so that it would equal one ten-millionth of the distance from the north pole to the equator along the meridian of the earth running near Dunkirk in France and Barcelona in Spain.

The metric unit of mass, called the "gram," was defined as the mass of one cubic centimeter (a cube that is 1/100 of a meter on each side) of water at its temperature of maximum density. The cubic decimeter (a cube 1/10 of a meter on each side) was chosen as the unit of fluid capacity. This measure was given the name "liter."

Although the metric system was not accepted with enthusiasm at first, adoption by other nations occurred steadily after France made its use compulsory in 1840. The standardized character and decimal features of the metric system made it well suited to scientific and engineering work. Consequently, it is not surprising that the rapid spread of the system coincided with an age of rapid technological development. In the United States, by Act of Congress in 1866, it was made "lawful throughout the United States of America to employ the weights and measures of the metric system in all contracts, dealings or court proceedings."

By the late 1860's, even better metric standards were needed to keep pace with scientific advances. In 1875, an international treaty, the "Treaty of the Meter," set up well-defined metric standards for length and mass, and established permanent machinery to recommend and adopt further refinements in the metric system. This treaty, known as the Metric Convention, was signed by 17 countries, including the United States.

As a result of the Treaty, metric standards were constructed and distributed to each nation that ratified the Convention. Since 1893, the internationally agreed-to metric standards have served as the fundamental weights and measures standards of the United States.

By 1900 a total of 35 nations—including the major nations of continental Europe and most of South America—had officially accepted the metric system. Today, with the exception of the United States and a few small countries, the entire world is using predominantly the metric system or is committed to such use. In 1971 the Secretary of Commerce, in transmitting to Congress the results of a 3-year study authorized by the Metric Study Act of 1968, recommended that the U.S. change to predominant use of the metric system through a coordinated national program. The Congress is now considering this recommendation.

The International Bureau of Weights and Measures located at Sevres, France, serves as a permanent secretariat for the Metric Convention, coordinating the exchange of information about the use and refinement of the metric system. As measurement science develops more precise and easily reproducible ways of defining the measurement units, the General Conference of Weights and Measures—the diplomatic organization made up of adherents to the Convention—meets periodically to ratify improvements in the system and the standards.

In 1960, the General Conference adopted an extensive revision and simplification of the system. The name *Le Système International d'Unités* (International System of Units), with the international abbreviation SI, was adopted for this modernized metric system. Further improvements in and additions to SI were made by the General Conference in 1964, 1968, and 1971.

A BRIEF HISTORY of measurement systems

WITH A CHART OF THE MODERNIZED METRIC SYSTEM

> **"Weights and measures may be ranked among the necessaries of life to every individual of human society. They enter into the economical arrangements and daily concerns of every family. They are necessary to every occupation of human industry; to the distribution and security of every species of property; to every transaction of trade and commerce; to the labors of the husbandman; to the ingenuity of the artificer; to the studies of the philosopher; to the researches of the antiquarian, to the navigation of the mariner, and the marches of the soldier; to all the exchanges of peace, and all the operations of war. The knowledge of them, as in established use, is among the first elements of education, and is often learned by those who learn nothing else, not even to read and write. This knowledge is riveted in the memory by the habitual application of it to the employments of men throughout life."**
>
> **JOHN QUINCY ADAMS**
> **Report to the Congress, 1821**

Weights and measures were among the earliest tools invented by man. Primitive societies needed rudimentary measures for many tasks: constructing dwellings of an appropriate size and shape, fashioning clothing, or bartering food or raw materials.

Man understandably turned first to parts of his body and his natural surroundings for measuring instruments. Early Babylonian and Egyptian records and the Bible indicate that length was first measured with the forearm, hand, or finger and that time was measured by the periods of the sun, moon, and other heavenly bodies. When it was necessary to compare the capacities of containers such as gourds or clay or metal vessels, they were filled with plant seeds which were then counted to measure the volumes. When means for weighing were invented, seeds and stones served as standards. For instance, the "carat," still used as a unit for gems, was derived from the carob seed.

As societies evolved, weights and measures became more complex. The invention of numbering systems and the science of mathematics made it possible to create whole systems of weights and measures suited to trade and commerce, land division, taxation, or scientific research. For these more sophisticated uses it was necessary not only to weigh and measure more complex things—it was also necessary to do it accurately time after time and in different places. However, with limited international exchange of goods and communication of ideas, it is not surprising that different systems for the same purpose developed and became established in different parts of the world—even in different parts of a single continent.

THE ENGLISH SYSTEM

The measurement system commonly used in the United States today is nearly the same as that brought by the colonists from England. These measures had their origins in a variety of cultures—Babylonian, Egyptian, Roman, Anglo-Saxon, and Norman-French. The ancient "digit," "palm," "span," and "cubit" units evolved into the "inch," "foot," and "yard" through a complicated transformation not yet fully understood.

Roman contributions include the use of the number 12 as a base (our foot is divided into 12 inches) and words from which we derive many of our present weights and measures names. For example, the 12 divisions of the Roman "pes," or foot, were called *unciae*. Our words "inch" and "ounce" are both derived from that Latin word.

The "yard" as a measure of length can be traced back to the early Saxon kings. They wore a sash or girdle around the waist that could be removed and used as a convenient measuring device. Thus the word "yard" comes from the Saxon word "gird" meaning the circumference of a person's waist.

Standardization of the various units and their combinations into a loosely related system of weights and measures sometimes occurred in fascinating ways. Tradition holds that King Henry I decreed that the yard should be the distance from the tip of his nose to the end of his thumb. The length of a furlong (or furrow-long) was established by early Tudor rulers as 220 yards. This led Queen Elizabeth I to declare, in the 16th century, that henceforth the traditional Roman mile of 5 000 feet would be replaced by one of 5 280 feet, making the mile exactly 8 furlongs and providing a convenient relationship between two previously ill-related measures.

Thus, through royal edicts, England by the 18th century had achieved a greater degree of standardization than the continental countries. The English units were well suited to commerce and trade because they had been developed and refined to meet commercial needs. Through colonization and dominance of world commerce during the 17th, 18th, and 19th centuries, the English system of weights and measures was spread to and established in many parts of the world, including the American colonies.

However, standards still differed to an extent undesirable for commerce among the 13 colonies. The need for greater uniformity led to clauses in the Articles of Confederation (ratified by the original colonies in 1781) and the Constitution of the United States (ratified in 1790) giving power to the Congress to fix uniform standards for

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

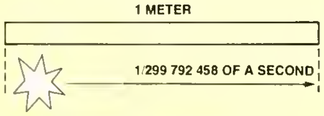
THE MODERNIZED metric system

THE INTERNATIONAL SYSTEM OF UNITS (SI) is a modernized version of the metric system established by international agreement. It provides a logical and interconnected framework for all measurements in science, industry, and commerce. Officially abbreviated SI, the system is built upon a foundation of seven base units, plus two supplementary units, which appear on this chart along with their definitions. All other SI units are derived from these units. Multiples and submultiples are expressed in a decimal system. Use of metric weights and measures was legalized in the United States in 1866, and since 1893 the yard and pound have been defined in terms of the meter and the kilogram. The base units for time, electric current, amount of substance, and luminous intensity are the same in both the inch-pound and metric systems.

LENGTH m

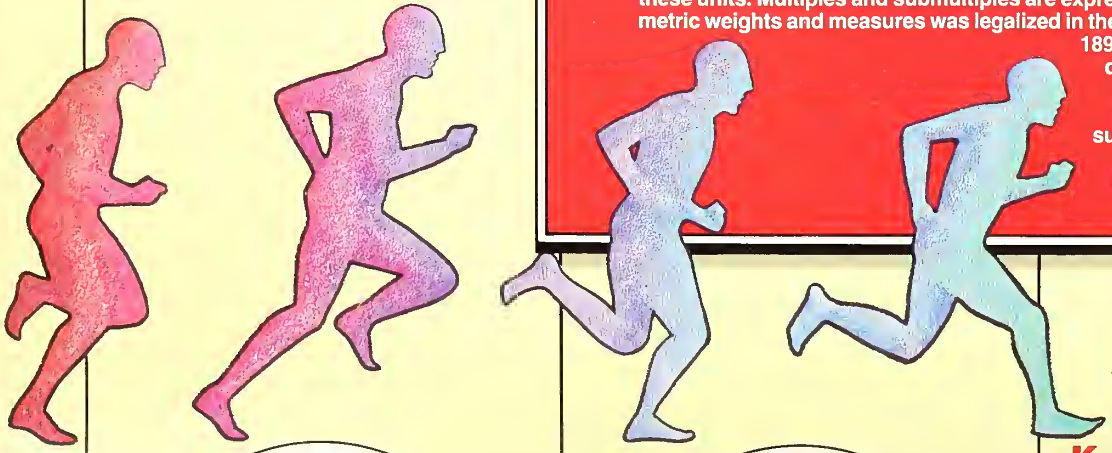
METER

The meter is the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second.



The speed of light in vacuum is 299 792 458 meters per second.

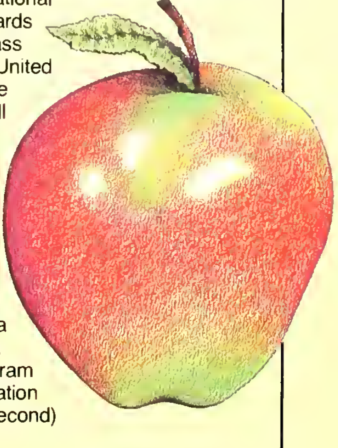
The SI unit of area is the **square meter** (m^2).
The SI unit of volume is the **cubic meter** (m^3).
The liter (1 cubic decimeter), although not an SI unit, is commonly used to measure fluid volume.



MASS kg

KILOGRAM

The standard for the unit of mass, the kilogram, is a cylinder of platinum-iridium alloy kept by the International Bureau of Weights and Measures at Paris. A duplicate in the custody of the National Bureau of Standards serves as the mass standard for the United States. This is the only base unit still defined by an artifact.



The SI unit of force is the **newton** (N). One newton is the force which, when applied to a 1-kilogram mass, will give the kilogram mass an acceleration of 1 (meter per second) per second.

$$1\ N = 1\ kg\cdot m/s^2$$

The SI unit for pressure is the **pascal** (Pa).

$$1\ Pa = 1\ N/m^2$$

The SI unit for work and energy of any kind is the **joule** (J).

$$1\ J = 1\ N\cdot m$$

The SI unit for power of any kind is the **watt** (W).

$$1\ W = 1\ J/s.$$

TIME s

SECOND

The second is defined as the duration of 9 192 631 770 cycles of the radiation associated with a specified transition of the cesium-133

ELECTRIC CURRENT A

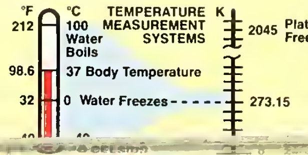
AMPERE

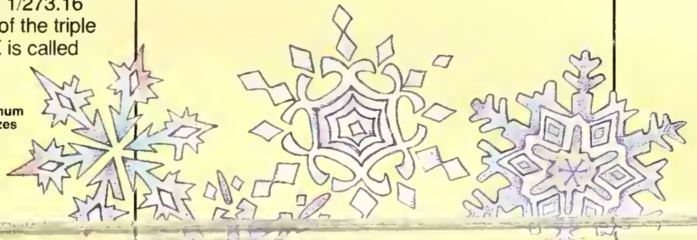
The ampere is defined as that current which, if maintained in each of two long parallel wires separated by one meter in free space, would

TEMPERATURE K

KELVIN

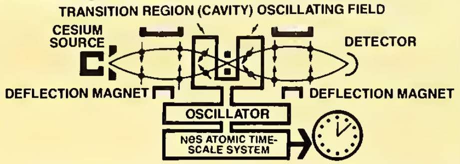
The kelvin is defined as the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. The temperature 0 K is called "absolute zero."





ated with a specified transition of the cesium-133

atoms as they pass through a system of magnets and a resonant cavity into a detector.



Schematic diagram of an atomic beam spectrometer or "clock." Only those atoms whose magnetic moments are "flipped" in the transition region reach the detector. When 9 192 631 770 oscillations have occurred, the clock indicates one second has passed.

The number of periods or cycles per second is called frequency. The SI unit for frequency is the **hertz** (Hz). One hertz equals one cycle per second.

The SI unit for speed is the **meter per second** (m/s).

The SI unit for acceleration is the **(meter per second) per second** (m/s²).

Standard frequencies and correct time are broadcast from WWV, WWVB, and WWVH, and stations of the U.S. Navy. Many shortwave receivers pick up WWV and WWVH, on frequencies of 2.5, 5, 10, 15, and 20 megahertz.

COMMON CONVERSIONS
Accurate to Six Significant Figures

Symbol	When You Know Number Of	Multiply by	To Find Number Of	Symbol
in	inches	[A]25.4	[B]millimeters	mm
ft	feet	[A]0.3048	meters	m
yd	yards	[A]0.9144	meters	m
mi	miles	1.609 34	kilometers	km
yd²	square yards	0.836 127	square meters	m²
	acres	0.404 686	[C]hectares	he
yd³	cubic yards	0.764 555	cubic meters	m³
qt	quarts (lq)	0.946 353	[D]liters	L
oz	ounces (avdp)	28.349 5	grams	g
lb	pounds (avdp)	[A]0.453 592 37	kilograms	kg
°F	degrees Fahrenheit	[A]5/9 (after subtracting 32)	degrees Celsius	°C
mm	millimeters	0.039 370 1	inches	in
m	meters	3.280 84	feet	ft
m	meters	1.093 61	yards	yd
km	kilometers	0.621 371	miles	mi
m²	square meters	1.195 99	square yards	yd²
ha	[C]hectares	2.471 05	acres	
m³	cubic meters	1.307 95	cubic yards	yd³
L	[D]liters	1.056 69	quarts (lq)	qt
g	grams	0.035 274 0	ounces (avdp)	oz
kg	kilograms	2.204 62	pounds (avdp)	lb
°C	degrees Celsius	[A]9/5 (then add 32)	degrees Fahrenheit	°F

[A] exact

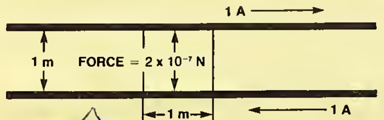
[B] for example, 1 in = 25.4 mm, so 3 inches would be $(3\text{ in})(25.4\frac{\text{mm}}{\text{in}}) = 76.2\text{ mm}$

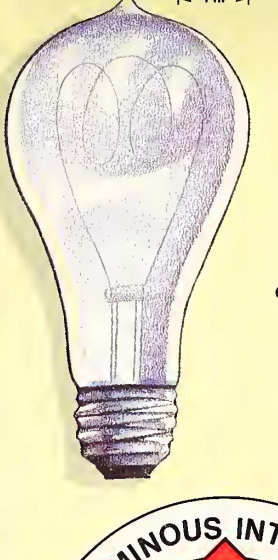
[C] hectare is a common name for 10,000 square meters (= 1 hm²)

[D] liter is a common name for fluid volume of 0.001 cubic meter

Note: Most symbols are written with lower case letters; exceptions are L for liter and units named after persons for which the symbols are capitalized. Periods are not used with any symbols.

each meter of length.





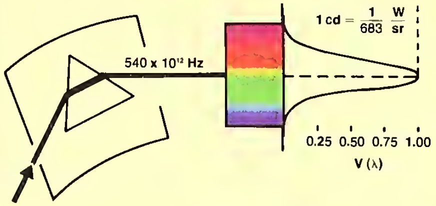
The SI unit of electric potential is the **volt** (V).
1 V = 1 W/A

The SI unit of electric resistance is the **ohm** (Ω).
1 Ω = 1 V/A

LUMINOUS INTENSITY
cd

C A N D E L A

The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} hertz (Hz) and that has a radiant intensity in that direction of 1/683 watt per steradian.

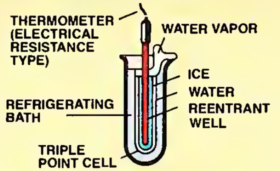


Radiation at frequencies other than 540 x 10^{12} Hz is also measured in candelas in accordance with the standard luminous efficiency, V(λ), curve that peaks at 540 x 10^{12} Hz (yellow-green).

FAHRENHEIT KELVIN

On the commonly used Celsius temperature scale, water freezes at about 0 °C and boils at about 100 °C. The °C is defined as an interval of 1 K, and the Celsius temperature 0 °C is defined as 273.15 K.

1.8 Fahrenheit degrees are equal to 1.0 Celsius degree or 1.0 kelvin; the Fahrenheit scale uses 32 °F as the temperature corresponding to 0 °C.



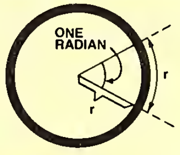
The standard temperature at the triple point of water is provided by a special cell, an evacuated glass cylinder containing pure water. When the cell is cooled until a mantle of ice forms around the reentrant well, the temperature at the interface of solid, liquid, and vapor is 273.16 K. Thermometers to be calibrated are placed in the reentrant well.

SUPPLEMENTARY UNITS

PLANE ANGLE
rad

R A D I A N

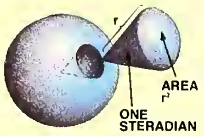
The radian is the plane angle with its vertex at the center of a circle that is subtended by an arc equal in length to the radius.

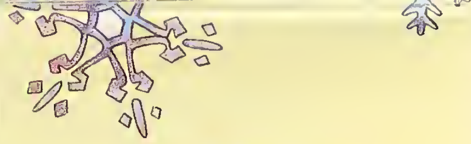


SOLID ANGLE
sr

S T E R A D I A N

The steradian is the solid angle with its vertex at the center of a sphere that is subtended by an area of the spherical surface equal to that of a square with sides equal in length to the radius.





AMOUNT OF SUBSTANCE
mol

M O L E

The mole is the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.

When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

The SI unit of concentration (of amount of substance) is the **mole per cubic meter** (mol/m³).

MULTIPLES AND PREFIXES
These Prefixes May Be Applied To All SI Units*

Multiples and Submultiples		Prefixes	Symbols
1 000 000 000 000 000 000	=	10^{18} exa (ĕx a)	E
1 000 000 000 000 000	=	10^{15} peta (pĕt a)	P
1 000 000 000 000	=	10^{12} tera (tĕr a)	T
1 000 000 000	=	10^{9} giga (jĭ ga)	G
1 000 000	=	10^{6} mega (mĕg a)	M
1 000	=	10^{3} kilo (kĭl ō)	k
100	=	10^{2} hecto (hĕk tō)	h
10	=	10^{1} deka (dĕk a)	da
1	=	10^{0}	
0.1	=	10^{-1} deci (dĕs ĭ)	d
0.01	=	10^{-2} centi (sĕn tĭ)	c
0.001	=	10^{-3} milli (mĭl ĭ)	m
0.000 001	=	10^{-6} micro (mī krō)	μ
0.000 000 001	=	10^{-9} nano (năn ō)	n
0.000 000 000 001	=	10^{-12} pico (pē kō)	p
0.000 000 000 000 001	=	10^{-15} femto (fĕm tō)	f
0.000 000 000 000 000 001	=	10^{-18} atto (ăt tō)	a

*apply to gram in case of mass

National Bureau of Standards
Special Publication 304A (Revised March 1986)
For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402

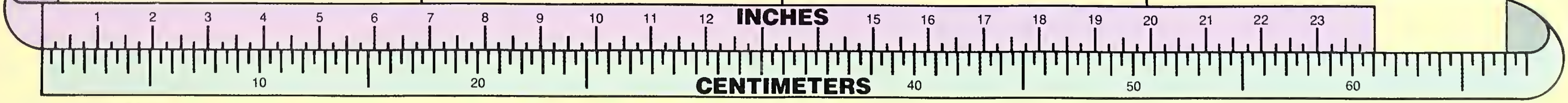
REFERENCES

NBS Special Publication 330, latest edition. International System of Units (SI), available by purchase from the Superintendent of Documents, Government Printing Office, Washington, DC 20402

ASTM Standard for Metric Practice. E380-84. available by purchase from the American Society for Testing and Materials. 1916 Race St., Philadelphia, PA 19103

IEEE Standard Metric Practice, IEEE Standard 268-1982. available by purchase from the Institute of Electrical and Electronics Engineers, Inc., 345 East 47th St., New York, NY 10017

SI Units and Recommendations for the Use of Their Multiples and of Certain Other Units, available by purchase from the American National Standards Institute. 1430 Broadway, New York, NY 10018, order as ISO Standard 1000.

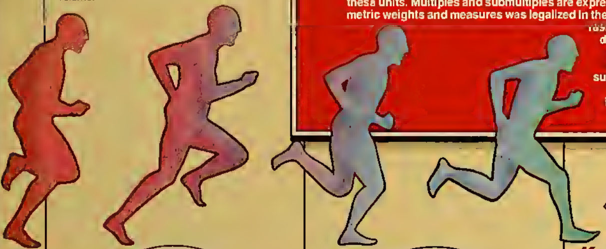


Note: Not to Scale

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE MODERNIZED metric system

THE INTERNATIONAL SYSTEM OF UNITS (SI) is a modernized version of the metric system established by international agreement. It provides a logical and interconnected framework for all measurements in science, industry, and commerce. Officially abbreviated SI, the system is built upon a foundation of seven base units, plus two supplementary units, which appear on this chart along with their definitions. All other SI units are derived from these units. Multiples and submultiples are expressed in a decimal system. Use of metric weights and measures was legalized in the United States in 1866, and since 1893 the yard and pound have been defined in terms of the meter and the kilogram. The base units for time, electric current, amount of substance, and luminous intensity are the same in both the inch-pound and metric systems.



LENGTH
m

METER

The meter is the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second.

The speed of light in vacuum is 299 792 458 meters per second.

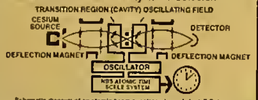
The SI unit of area is the **square meter** (m²).

The SI unit of volume is the **cubic meter** (m³). The liter (1 cubic decimeter), although not an SI unit, is commonly used to measure fluid volume.

TIME
s

SECOND

The second is defined as the duration of 9 192 631 770 cycles of the radiation associated with a specified transition of the cesium-133 atom. It is realized by tuning an oscillator to the resonance frequency of cesium-133 atoms as they pass through a system of magnets and a resonant cavity into a detector.



Schematic diagram of an atomic beam spectrometer or "clock." Only those atoms whose magnetic moments are "flipped" in the transition region reach the detector. When 9 192 631 770 oscillations have occurred, the clock indicates one second has passed.

The number of periods or cycles per second is called frequency. The SI unit for frequency is the **hertz** (Hz). One hertz equals one cycle per second.

The SI unit for speed is the **meter per second** (m/s).

The SI unit for acceleration is the **(meter per second) per second** (m/s²).

Standard frequencies and correct time are broadcast from WWV, WWVB, and WWVH, and stations of the U.S. Navy. Many shortwave receivers pick up WWV and WWVH, on frequencies of 2.5, 5, 10, 15, and 20 megahertz.

COMMON CONVERSIONS
Accurate to Six Significant Figures

	When You Know		To Find	
Symbol	Number Of	Multiply by	Number Of	Symbol
in	inches	*25.4	millimeters	mm
ft	feet	*0.3048	meters	m
yd	yards	*0.9144	meters	m
mi	miles	1.609 34	kilometers	km
yd²	square yards	0.836 127	square meters	m²
	acres	0.404 686	hectares	ha
yd³	cubic yards	0.764 555	cubic meters	m³
qt	quarts (lq)	0.946 353	liters	L
oz	ounces (avdp)	28.349 5	grams	g
lb	pounds (avdp)	*0.453 592 37	kilograms	kg
°F	degrees Fahrenheit	*5/9 (after subtracting 32)	degrees Celsius	°C
mm	millimeters	0.039 370 1	inches	in
m	meters	3.280 84	feet	ft
m	meters	1.093 61	yards	yd
km	kilometers	0.621 371	miles	mi
m²	square meters	1.195 99	square yards	yd²
ha	hectares	2.471 05	acres	
m³	cubic meters	1.307 95	cubic yards	yd³
L	liters	1.056 69	quarts (lq)	qt
g	grams	0.035 274 0	ounces (avdp)	oz
kg	kilograms	2.204 62	pounds (avdp)	lb
°C	degrees Celsius	*9/5 (then add 32)	degrees Fahrenheit	°F

*exact

For example: 1 in = 25.4 mm, so 3 inches would be (3 in)(25.4 mm/in) = 76.2 mm

hectare is a common name for 10 000 square meters (1 hm²)

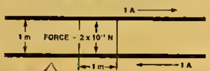
liter is a common name for fluid volume of 0.001 cubic meter

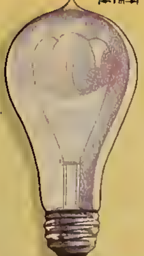
Note: Most symbols are written with lower case letters; exceptions are L for liter and units named after persons for which the symbols are capitalized. Periods are not used with any symbols.

ELECTRIC CURRENT
A

AMPERE

The ampere is defined as that current which, if maintained in each of two long parallel wires separated by one meter in free space, would produce a force between the two wires (due to their magnetic fields) of 2×10^{-7} newton for each meter of length.





The SI unit of electric potential is the **volt** (V).
1 V = 1 W/A

The SI unit of electric resistance is the **ohm** (Ω).
1 Ω = 1 V/A

LUMINOUS INTENSITY
cd

CANDELA

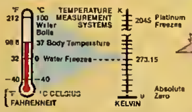
The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz (Hz) and that has a radiant intensity in that direction of 1/683 watt per steradian.

Radiation at frequencies other than 540×10^{12} Hz is also measured in candelas in accordance with the standard luminous efficiency, V(λ), curve that peaks at 540×10^{12} Hz (yellow-green).

TEMPERATURE
K

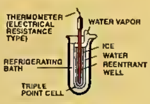
KELVIN

The kelvin is defined as the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. The temperature 0 K is called "absolute zero."

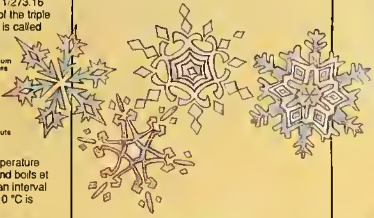


On the commonly used Celsius temperature scale, water freezes at about 0 °C and boils at about 100 °C. The °C is defined as an interval of 1 K, and the Celsius temperature 0 °C is defined as 273.15 K.

1.8 Fahrenheit degrees are equal to 1.0 Celsius degree or 1.0 kelvin; the Fahrenheit scale uses 32 °F as the temperature corresponding to 0 °C.



The standard temperature at the triple point of water is provided by a special cell, an evacuated glass cylinder containing pure water. When the cell is cooled until a mantle of ice forms around the reentrant well, the temperature at the interface of solid, liquid, and vapor is 273.16 K. Thermometers to be calibrated are placed in the reentrant well.



SUPPLEMENTARY UNITS

PLANE ANGLE
rad

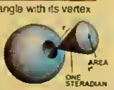
RADIAN

The radian is the plane angle with its vertex at the center of a circle that is subtended by an arc equal in length to the radius.

SOLID ANGLE
sr

STERADIAN

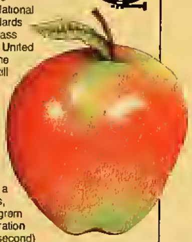
The steradian is the solid angle with its vertex at the center of a sphere that is subtended by an area of the spherical surface equal to that of a square with sides equal in length to the radius.



MASS
kg

KILOGRAM

The standard for the unit of mass, the kilogram, is a cylinder of platinum-iridium alloy kept by the International Bureau of Weights and Measures at Paris. A duplicate in the custody of the National Bureau of Standards serves as the mass standard for the United States. This is the only base unit still defined by an artifact.



The SI unit of force is the **newton** (N). One newton is the force which, when applied to a 1-kilogram mass, will give the kilogram mass an acceleration of 1 (meter per second) per second.

1 N = 1 kg·m/s²

The SI unit for pressure is the **pascal** (Pa).
1 Pa = 1 N/m²

The SI unit for work and energy of any kind is the **joule** (J).
1 J = 1 N·m

The SI unit for power of any kind is the **watt** (W).
1 W = 1 J/s.

AMOUNT OF SUBSTANCE
mol

MOLE

The mole is the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.

When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

The SI unit of concentration (of amount of substance) is the **mole per cubic meter** (mol/m³).

MULTIPLES AND PREFIXES
These Prefixes May Be Applied To All SI Units*

Multiples and Submultiples	Prefixes	Symbols
1 000 000 000 000 000 000 = 10^{18}	exa (ex′ a)	E
1 000 000 000 000 000 = 10^{15}	peta (pet′ a)	P
1 000 000 000 000 = 10^{12}	tera (ter′ a)	T
1 000 000 000 = 10^{9}	giga (ji′ ga)	G
1 000 000 = 10^{6}	mega (meg′ a)	M
1 000 = 10^{3}	kilo (kil′ ō)	k
100 = 10^{2}	hecto (hek′ tō)	h
10 = 10^{1}	deka (dek′ a)	da
1 = 10^{0}		
0.1 = 10^{-1}	deci (des′ i)	d
0.01 = 10^{-2}	centi (sen′ ti)	c
0.001 = 10^{-3}	milli (mil′ i)	m
0.000 001 = 10^{-6}	micro (mi′ krō)	μ
0.000 000 001 = 10^{-9}	nano (nan′ ō)	n
0.000 000 000 001 = 10^{-12}	pico (pe′ kō)	p
0.000 000 000 000 001 = 10^{-15}	femto (fem′ tō)	f
0.000 000 000 000 000 001 = 10^{-18}	atto (at′ tō)	a

*apply to gram in case of mass

National Bureau of Standards
Special Publication 304A (Revised March [illegible])
For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402

REFERENCES
NBS Special Publication 330, [illegible] edition, International System of Units (SI), available by purchase from the Superintendent of Documents, Government Printing Office, Washington, DC 20402

ASTM Standard for Metric Practice, E380-[illegible], available by purchase from the American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103

IEEE Standard Metric Practice, IEEE Standard 268-[illegible], available by purchase from the Institute of Electrical and Electronics Engineers, Inc., 345 East 47th St., New York, NY 10017

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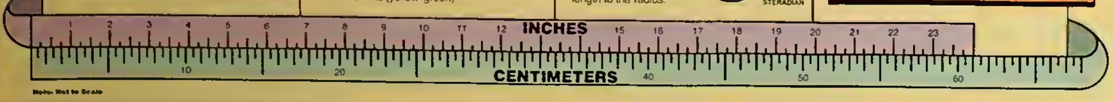


Note: Not to Scale

weights and measures. Today, standards supplied to all the States by the National Bureau of Standards assure uniformity throughout the country.

THE METRIC SYSTEM

The need for a single worldwide coordinated measurement system was recognized over 300 years ago. Gabriel Mouton, Vicar of St. Paul in Lyons, proposed in 1670 a comprehensive decimal measurement system based on the length of one minute of arc of a great circle of the earth. In 1671, Jean Picard, a French astronomer, proposed the length of a pendulum beating seconds as the unit of length. (Such a pendulum would have been fairly easily reproducible, thus facilitating the widespread distribution of uniform standards.) Other proposals were made, but over a century elapsed before any action was taken.

In 1790 in the midst of the French Revolution, the National Assembly of France requested the French Academy of Sciences to "deduce an invariable standard for all the measures and all the weights." The Commission appointed by the Academy created a system that was, at once, simple and scientific. The unit of length was to be a portion of the earth's circumference. Measures for capacity (volume) and mass (weight) were to be derived from the unit of length, thus relating the basic units of the system to each other and to nature. Furthermore, the larger and smaller versions of each unit were to be created by multiplying or dividing the basic units by 10 and its powers. This feature provided a great convenience to users of the system, by eliminating the need for such calculations as dividing by 16 (to convert ounces to pounds) or by 12 (to convert inches to feet). Similar calculations in the metric system could be performed simply by shifting the decimal point. Thus the metric system is a "base-10" or "decimal" system.

The Commission assigned the name *mètre*—meter—to the unit of length. This name was derived from the Greek word *metron,* meaning "a measure." The physical standard representing the meter was to be constructed so that it would equal one ten-millionth of the distance from the north pole to the equator along the meridian of the earth running near Dunkirk in France and Barcelona in Spain.

The metric unit of mass, called the "gram," was defined as the mass of one cubic centimeter (a cube that is 1/100 of a meter on each side) of water at its temperature of maximum density.

The cubic decimeter (a cube 1/10 of a meter on each side) was chosen as the unit of fluid capacity. This measure was given the name "liter."

Although the metric system was not accepted with enthusiasm at first, adoption by other nations occurred steadily after France made its use compulsory in 1840. The standardized character and decimal features of the metric system made it well suited to scientific and engineering work. Consequently, it is not surprising that the rapid spread of the system coincided with an age of rapid technological development. In the United States, by Act of Congress in 1866, it was made "lawful throughout the United States of America to employ the weights and measures of the metric system in all contracts, dealings or court proceedings."

By the late 1860's, even better metric standards were needed to keep pace with scientific advances. In 1875, an international treaty, the "Treaty of the Meter," set up well-defined metric standards for length and mass, and established permanent machinery to recommend and adopt further refinements in the metric system. This treaty, known as the Metric Convention, was signed by 17 countries, including the United States.

As a result of the Treaty, metric standards were constructed and distributed to each nation that ratified the Convention. Since 1893, the internationally agreed-to metric standards have served as the fundamental weights and measures standards of the United States.

By 1900 a total of 35 nations—including the major nations of continental Europe and most of South America—had officially accepted the metric system. In 1971 the Secretary of Commerce, in transmitting to Congress the results of a 3-year study authorized by the Metric Study Act of 1968, recommended that the U.S. change to predominant use of the metric system through a coordinated national program. The Congress responded by enacting the Metric Conversion Act of 1975. Today, with the exception of a few small countries, the entire world is using the metric system or is changing to such use.

The International Bureau of Weights and Measures located at Sèvres, France, serves as a permanent secretariat for the Meter Convention, coordinating the exchange of information about the use and refinement of the metric system. As measurement science develops more precise and easily reproducible ways of defining the measurement units, the General Conference on Weights and Measures—the diplomatic organization made up of adherents to the Convention—meets periodically to ratify improvements in the system and the standards.

In 1960, the General Conference adopted an extensive revision and simplification of the system. The name *Le Système International d'Unités* (International System of Units), with the international abbreviation SI, was adopted for this modernized metric system. Further improvements in and additions to SI were made by the General Conference in 1964, 1968, 1971, 1975, 1979, and 1983. ◆

A Brief HISTORY of Measurement Systems

WITH A CHART OF THE MODERN METRIC SYSTEM

> "Weights and measures may be ranked among the necessaries of life to every individual of human society. They enter into the economical arrangements and daily concerns of every family. They are necessary to every occupation of human industry; to the distribution and security of every species of property; to every transaction of trade and commerce; to the labors of the husbandman; to the ingenuity of the artificer; to the studies of the philosopher; to the researches of the antiquarian, to the navigation of the mariner, and the marches of the soldier; to all the exchanges of peace, and all the operations of war. The knowledge of them, as in established use; is among the first elements of education, and is often learned by those who learn nothing else, not even to read and write. This knowledge is riveted in the memory by the habitual application of it to the employments of men throughout life."
>
> *JOHN QUINCY ADAMS*
> *Report to the Congress, 1821*

Weights and measures were among the earliest tools invented by man. Primitive societies needed rudimentary measures for many tasks: constructing dwellings of an appropriate size and shape, fashioning clothing, and bartering food or raw materials.

Man understandably turned first to parts of his body and his natural surroundings for measuring instruments. Early Babylonian and Egyptian records, and the Bible, indicate that length was first measured with the forearm, hand, or finger and that time was measured by the periods of the sun, moon, and other heavenly bodies. When it was necessary to compare the capacities of containers such as gourds or clay or metal vessels, they were filled with plant seeds that were then counted to measure the volumes. With the development of scales as a means for weighing, seeds and stones served as standards. For instance, the "carat," still used as a mass unit for gems, is derived from the carob seed.

As societies evolved, measurements became more complex. The invention of numbering systems and the science of mathematics made it possible to create whole systems of measurement units suited to trade and commerce, land division, taxation, and scientific research. For these more sophisticated uses, it was necessary not only to weigh and measure more complex things -- it was also necessary to do it accurately time after time and in different places. However, with limited international exchange of goods and communication of ideas, it is not surprising that different systems for the same purpose developed and became established in different parts of the world -- even in different parts of the same country.

THE ENGLISH SYSTEM

The measurement system commonly used in the United States today is nearly the same as that brought by the colonists from England. These measures had their origins in a variety of cultures -- Babylonian, Egyptian, Roman, Anglo-Saxon, and Norman French. The ancient "digit," "palm," "span," and "cubit" units of length slowly lost preference to the length units "inch," "foot," and "yard."

Roman contributions include the use of 12 as a base number (the foot is divided into 12 inches) and the words from which we derive many of our present measurement unit names. For example, the 12 divisions of the Roman "pes," or foot, were called unciae. Our words "inch" and "ounce" are both derived from that Latin word.

The "yard" as a measure of length can be traced back to early Saxon kings. They wore a sash or girdle around the waist that could be removed and used as a convenient measuring device. The word "yard" comes from the Saxon word "gird" meaning the circumference of a person's waist.

Standardizing various units and combining them into loosely related systems of measurement units sometimes occurred in fascinating ways. Tradition holds that King Henry I decreed that a yard should be the distance from the tip of his nose to the end of his outstretched thumb. The length of a furlong (or furrow-long) was established by early Tudor rulers as 220 yards. This led Queen Elizabeth I to declare, in the 16th century, that henceforth the traditional Roman mile of 5000 feet would be replaced by one of 5280 feet, making the mile exactly eight furlongs and providing a convenient relationship between the furlong and the mile.

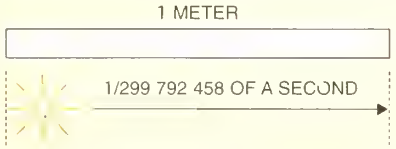
Thus, through royal edicts, England by the 18th century had achieved a greater degree of standardization than other European countries. The English units were well suited to commerce and trade because they had been developed and refined to meet commercial needs. Through English colonization and its dominance of world

length

METER

m

The meter is the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second.



The SI unit of speed is the **meter per second** (m/s).

The speed of light in vacuum is 299 792 458 meters per second.

The SI unit of acceleration is the **meter per second per second** (m/s^2).

The SI unit of area is the **square meter** (m^2). The SI unit of volume is the **cubic meter** (m^3). The liter (1 cubic decimeter), although not an SI unit, is accepted for use with the SI and is commonly used to measure fluid volume.

time

SECOND

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the modern metric system

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electric current

AMPERE

A

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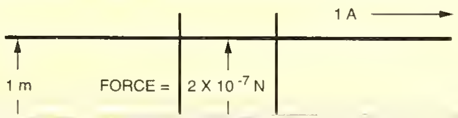


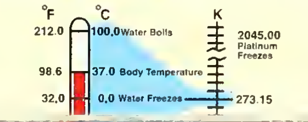
temperature

KELVIN

K

The kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. The temperature 0 K is commonly referred to as "absolute zero." On the widely used Celsius temperature scale, water freezes at 0 °C and boils at about 100 °C. One Celsius

TEMPERATURE MEASUREMENT SYSTEMS

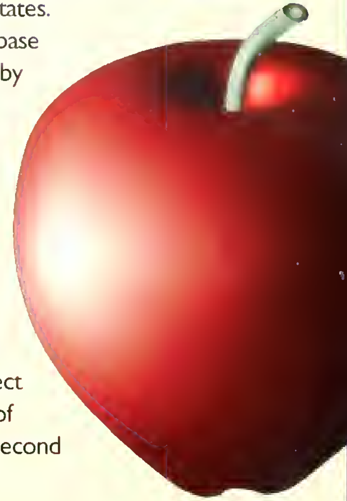


mass

KILOGRAM

kg

The standard for the unit of mass, the kilogram, is a cylinder of platinum-iridium alloy kept by the International Bureau of Weights and Measures near Paris. A duplicate in the custody of the National Institute of Standards and Technology serve as the mass standard for the United States. This is the only base unit still defined by an artifact.



The SI unit of force is the **newton** (N). One newton is a force that, applied to a one kilogram object, will give the object an acceleration of one meter per second per second.

$$1\ \text{N} = 1\ \text{kg}\cdot\text{m/s}^2$$

The weight of an object is the force exerted on it by gravity. Gravity gives a mass a downward acceleration of about 9.8 m/s^2.

The SI unit for pressure is the **pascal** (Pa).

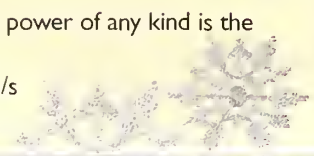
$$1\ \text{Pa} = 1\ \text{N/m}^2$$

The SI unit for work and energy of any kind is the **joule** (J).

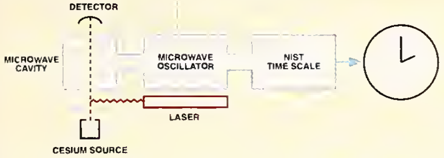
$$1\ \text{J} = 1\ \text{N}\cdot\text{m}$$

The SI unit for power of any kind is the **watt** (W).

$$1\ \text{W} = 1\ \text{J/s}$$



cavity, cesium atoms are forced into the right atomic state by a laser beam. A detector registers a signal only when the oscillator delivers just the right frequency to the microwave cavity causing transitions and changing the state of the atoms. This change in state is sensed at the detector.



The number of periods or cycles per second is called frequency. The SI unit for frequency is the **hertz** (Hz). One hertz is the same as one cycle per second. Standard frequencies and the correct time are broadcast by radio stations WWV and WWVB in Colorado, and WWVH in Hawaii. NIST delivers digital timing signals by telephone and through the Internet.

COMMON CONVERSIONS
Accurate to Six Significant Figures

Symbol	When you know number of	Multiply by	To find number of	Symbol
in	inches	25.4[A]	millimeters[B]	mm
ft	feet	0.304 8[A]	meters	m
yd	yards	0.914 4[A]	meters	m
mi	miles	1.609 34	kilometers	km
yd^2	square yards	0.836 127	square meters	m^3
	acres	0.404 686	hectares	ha
yd^3	cubic yards	0.764 555	cubic meters	m^3
qt	quarts (lq)	0.946 353	liters	L
oz	ounces(avdp)	28.349 5	grams	g
lb	pounds(avdp)	0.453 592 37[A]	kilograms	kg
°F	degrees Fahrenheit	5/9[A] (after subtracting 32)	degrees Celsius	°C
mm	millimeters	0.039 370 1	inches	in
m	meters	3.280 84	feet	ft
m	meters	1.093 61	yards	yd
km	kilometers	0.621 371	miles	mi
m^2	square meters	1.195 99	square yards	yd^3
ha	hectares[C]	2.471 045	acres	
m^3	cubic meters	1.307 95	cubic yards	yd^3
L	liters	1.056 69	quarts (lq)	qt
g	grams	0.035 274 0	ounces (avdp)	oz
kg	kilograms	2.204 62	pounds (avdp)	lb
°C	degrees Celsius	9/5[A] (then add 32)	degrees Fahrenheit	°F

[A] exact

[B] for example:1 in = 25.4 mm, so 3 inches would be (3 in)(25.4 $\frac{\text{mm}}{\text{in}}$) = 76.2 mm
Do not use more significant digits than justified by precision of original data.

[C] hectare is a common name for 10 000 square meters (1 hm²)

Note: Most symbols are written with lower case letters; exceptions are L for liter and units named after persons for which the symbols are capitalized. Periods are not used with any symbols.

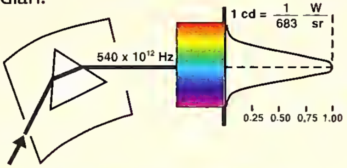
The SI unit of electric potential difference is the **volt** (V).
1 V = 1 W/A

The SI unit of electric resistance is the **ohm** (Ω).
1 Ω = 1 V/A

luminous intensity

CANDELA cd

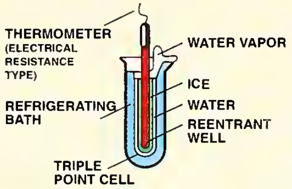
The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} hertz (Hz) and that has a radiant intensity in that direction of 1/683 watt per steradian.



Radiation at frequencies other than 540 x 10^{12} Hz is also measured in candelas in accordance with the standard luminous efficiency, $V(\lambda)$, curve that peaks at 540 x 10^{12} Hz (yellow-green).

interval of 1 K, and zero degrees Celsius is 273.15 K. An interval of one Celsius degree corresponds to an interval of 1.8 Fahrenheit degrees on the Fahrenheit temperature scale.

The standard temperature at the triple point of water is provided by a special cell, an evacuated glass cylinder containing pure water. When the cell is cooled enough so that a mantle of ice forms around the reentrant well, the temperature at the interface of solid, liquid, and vapor is 273.16 K. Thermometers to be calibrated are placed in the reentrant well.



SI DERIVED UNITS WITH SPECIAL NAMES AND SYMBOLS

Derived quantity	Name	Symbol	Expression in terms of other SI units	Expression in terms of SI base units
plane angle	radian	rad		$m \cdot m^{-1} = 1$
solid angle	steradian	sr		$m^2 \cdot m^{-2} = 1$
frequency	hertz	Hz		s^{-1}
force	newton	N		$m \cdot kg \cdot s^{-2}$
pressure, stress	pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
energy, work,	joule	J	N·m	$m^2 \cdot kg \cdot s^{-2}$
power, radiant flux	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
electric charge	coulomb	C		s·A
electric potential difference	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} A^{-1}$
capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
magnetic flux	weber	Wb	V·s	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
Celsius temperature	degree Celsius	°C		K
luminous flux	lumen	lm	cd·sr	cd·sr
illuminance	lux	lx	lm/m^2	$m^{-2} \cdot cd \cdot sr$
radionuclide activity	becquerel	8q		s^{-1}
absorbed dose	gray	Gy	J/kg	$m^2 \cdot s^{-2}$
dose equivalent	sievert	5v	J/kg	$m^2 \cdot s^{-2}$

REFERENCES

NIST Special Publication 330, latest edition, "International System of Units (SI)," available by purchase from the Superintendent of Documents, U.S. Government Printing Office Mail Stop. SSOP, Washington, DC 20402-9328

IEEE/ASTM SI 10, latest edition, "Standard for Use of the International System of Units (SI): The Modern Metric System," available by purchase from:
IEEE, 345 East 47th Street, New York, NY 10017-2394
ASTM, 100 Bar Harbor Drive West Conshohocken, PA 19428-2959

amount of substance

MOLE mol

The mole is the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.

When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

The SI unit of concentration (of amount of substance) is the **mole per cubic meter** (mol/m^3).

PREFIXES
May be Applied to All SI Units*

Multiples and Submultiples	Prefixes	Symbols
1000 000 000 000 000 000 000 000 = 10^{24}	yotta	Y
1000 000 000 000 000 000 000 = 10^{21}	zetta	Z
1000 000 000 000 000 000 = 10^{18}	exa	E
1000 000 000 000 000 = 10^{15}	peta	P
1000 000 000 000 = 10^{12}	tera	T
1000 000 000 = 10^{9}	giga	G
1000 000 = 10^{6}	mega	M
1000 = 10^{3}	kilo	k
100 = 10^{2}	hecto	h
10 = 10^{1}	deka	da
1 = 10^{0}		
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	µ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a
0.000 000 000 000 000 000 001 = 10^{-21}	zepto	z
0.000 000 000 000 000 000 000 001 = 10^{-24}	yocto	y

*apply to gram in case of mass

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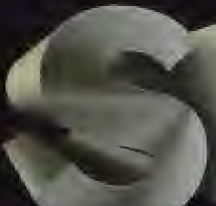


the modern metric system

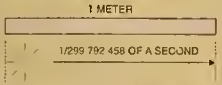
The International System of Units (SI), the modern version of the metric system, is established by international agreement. It provides a logical and interconnected framework for all measurements in science, industry, and commerce. Officially abbreviated SI, the system is built upon a foundation of seven base units, shown on this chart along with their descriptions. All other SI units are derived from these units. Multiples and submultiples are expressed using a decimal system. Use of metric units was legalized in the United States in 1866. Since 1893 the yard and pound have been defined in terms of the meter and the kilogram. The base units for time, electric current, amount of substance, and luminous intensity are the same in both the inch-pound and metric systems.

length

METER

m

The meter is the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second.



The SI unit of speed is the **meter per second** (m/s).

The speed of light in vacuum is 299 792 458 meters per second.

The SI unit of acceleration is the **meter per second per second** (m/s^2).

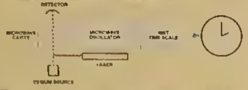
The SI unit of area is the **square meter** (m^2). The SI unit of volume is the **cubic meter** (m^3). The liter (1 cubic decimeter), although not an SI unit, is accepted for use with the SI and is commonly used to measure fluid volume.

time

SECOND

s

The second is the duration of 9 192 631 770 cycles of the radiation associated with a specific transition of the cesium 133 atom. The second is realized by tuning an oscillator to the resonance frequency associated with the above definition. Just before entering a microwave cavity, cesium atoms are forced into the right atomic state by a laser beam. A detector registers a signal only when the oscillator delivers just the right frequency to the microwave cavity causing transitions and changing the state of the atoms. This change in state is sensed at the detector.



The number of periods or cycles per second is called frequency. The SI unit for frequency is the **hertz** (Hz). One hertz is the same as one cycle per second. Standard frequencies and the correct time are broadcast by radio stations WWV and WWVB in Colorado, and WWVH in Hawaii. NIST delivers digital timing signals by telephone and through the Internet.

COMMON CONVERSIONS
Accurate to Six Significant Figures

Symbol	When you know number of	Multiply by	To find number of	Symbol
in	inches	25.4*	millimeters†	mm
ft	feet	0.304 8*	meters	m
yd	yards	0.914 4*	meters	m
mi	miles	1.609 34	kilometers	km
yd^2	square yards	0.836 127	square meters	m^2
	acres	0.404 686	hectares	ha
yd^3	cubic yards	0.764 555	cubic meters	m^3
qt	quarts (lq)	0.946 353	liters	L
oz	ounces (avdp)	28.349 5	grams	g
lb	pounds (avdp)	0.453 592 37*	kilograms	kg
°F	degrees Fahrenheit	5/9* (after subtracting 32)	degrees Celsius	°C
mm	millimeters	0.039 370 1	inches	in
m	meters	3.280 84	feet	ft
m	meters	1.093 61	yards	yd
km	kilometers	0.621 371	miles	mi
m^2	square meters	1.195 99	square yards	yd^2
ha	hectares‡	2.471 05	acres	
m^3	cubic meters	1.307 95	cubic yards	yd^3
L	liters	1.056 69	quarts (lq)	qt
g	grams	0.035 274 0	ounces (avdp)	oz
kg	kilograms	2.204 62	pounds (avdp)	lb
°C	degrees Celsius	9/5* (then add 32)	degrees Fahrenheit	°F

*exact
†for example, 1 in = 25.4 mm, so 3 inches would be (3 in)(25.4 mm/in) = 76.2 mm
[illegible]
‡hectare is a common name for 10 000 square meters (1 hm^2)

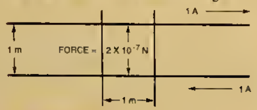
Note: Most symbols are written with lower case letters; exceptions are L for liter and units named after persons for which the symbols are capitalized. Periods are not used with any symbols.

electric current

AMPERE

A

The ampere is that current which, if maintained in each of two infinitely long parallel wires separated by one meter in free space, would produce a force between the two wires (due to their magnetic fields) of 2×10^{-7} newtons for each meter of length.



The SI unit of electric potential difference is the **volt** (V).
1 V = 1 W/A

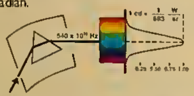
The SI unit of electric resistance is the **ohm** (Ω).
1 Ω = 1 V/A

luminous intensity

CANDELA

cd

The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz (Hz) and that has a radiant intensity in that direction of 1/683 watt per steradian.



Radiation at frequencies other than 540×10^{12} Hz is also measured in candelas in accordance with the standard luminous efficiency, $V(\lambda)$, curve that peaks at 540×10^{12} Hz (yellow-green).

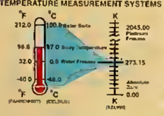
temperature

KELVIN

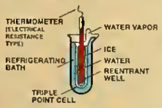
K

The kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. The temperature 0 K is commonly referred to as "absolute zero." On the widely used Celsius temperature scale, water freezes at 0 °C and boils at about 100 °C. One Celsius degree is an interval of 1 K, and zero degrees Celsius is 273.15 K. An interval of one Celsius degree corresponds to an interval of 1.8 Fahrenheit degrees on the Fahrenheit temperature scale.

TEMPERATURE MEASUREMENT SYSTEMS



The standard temperature at the triple point of water is provided by a special cell, an evacuated glass cylinder containing pure water. When the cell is cooled enough so that a mantle of ice forms around the reentrant well, the temperature at the interface of solid, liquid, and vapor is 273.16 K. Thermometers to be calibrated are placed in the reentrant well.



SI DERIVED UNITS
WITH SPECIAL NAMES AND SYMBOLS

Derived quantity	Name	Symbol	Expression in terms of other SI units	Expression in terms of SI base units
plane angle	radian	rad		m·m^{-1} = 1
solid angle	steradian	sr		m^2·m^{-2} = 1
frequency	hertz	Hz		s^{-1}
force	newton	N		m·kg·s^{-2}
pressure, stress	pascal	Pa	N/m^2	m^{-1}·kg·s^{-2}
energy, work	joule	J	N·m	m^2·kg·s^{-2}
power, radiant flux	watt	W	J/s	m^2·kg·s^{-3}
electric charge	coulomb	C		s·A
electric potential difference	volt	V	W/A	m^2·kg·s^{-3}·A^{-1}
capacitance	farad	F	C/V	m^{-2}·kg^{-1}·s^4·A^2
electric resistance	ohm	Ω	V/A	m^2·kg·s^{-3}·A^{-2}
electric conductance	siemens	S	A/V	m^{-2}·kg^{-1}·s^3·A^2
magnetic flux	weber	Wb	V·s	m^2·kg·s^{-2}·A^{-1}
magnetic flux density	tesla	T	Wb/m^2	kg·s^{-2}·A^{-1}
inductance	henry	H	Wb/A	m^2·kg·s^{-2}·A^{-2}
Celsius temperature	degree Celsius	°C		K
luminous flux	lumen	lm	cd·sr	cd·sr
illuminance	lux	lx	lm/m^2	m^{-2}·cd·sr
radionuclide activity	becquerel	Bq		s^{-1}
absorbed dose	gray	Gy	J/kg	m^2·s^{-2}
dose equivalent	sievert	Sv	J/kg	m^2·s^{-2}

REFERENCES
NIST Special Publication 330 [illegible] edition, "International System of Units (SI)," available for purchase from the Superintendent of Documents, U.S. Government Printing Office, [illegible] Washington, DC [illegible]

[illegible] edition, "Standard for Use of the International System of Units (SI): The Modern Metric System," available for purchase from:
[illegible]
[illegible]

mass

KILOGRAM

kg

The standard for the unit of mass, the kilogram, is a cylinder of platinum-iridium alloy kept by the International Bureau of Weights and Measures near Paris. A duplicate in the custody of the National Institute of Standards and Technology serves as the mass standard for the United States. This is the only base unit still defined by an artifact.

The SI unit of force is the **newton** (N). One newton is a force that, applied to a one kilogram object, will give the object an acceleration of one meter per second per second.

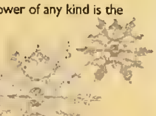
1 N = 1 kg·m/s^2

The weight of an object is the force exerted on it by gravity. Gravity gives a mass a downward acceleration of about 9.8 m/s^2.

The SI unit for pressure is the **pascal** (Pa).
1 Pa = 1 N/m^2

The SI unit for work and energy of any kind is the **joule** (J).
1 J = 1 N·m

The SI unit for power of any kind is the **watt** (W).
1 W = 1 J/s



amount of substance

MOLE

mol

The mole is the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.

When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

The SI unit of concentration (of amount of substance) is the **mole per cubic meter** (mol/m^3).

PREFIXES
May be Applied to All SI Units*

Multiples and Submultiples	Prefixes	Symbols
1 000 000 000 000 000 000 000 000 = 10^{24}	yotta	Y
1 000 000 000 000 000 000 000 = 10^{21}	zetta	Z
1 000 000 000 000 000 000 = 10^{18}	exa	E
1 000 000 000 000 000 = 10^{15}	peta	P
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto	h
10 = 10^{1}	deka	da
1 = 10^{0}		
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	µ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a
0.000 000 000 000 000 000 001 = 10^{-21}	zepto	z
0.000 000 000 000 000 000 000 001 = 10^{-24}	yocto	y

*apply to gram in case of mass

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commerce during the 17th, 18th, and 19th centuries, the English system of measurement units became established in many parts of the world, including the American colonies.

However, standards still differed to an extent undesirable for commerce, even among the 13 American colonies. The need for greater uniformity led to clauses in the Articles of Confederation (ratified by the original colonies in 1781) and the Constitution of the United States (ratified in 1790) that gave Congress the power to fix uniform standards for weights and measures. Today, standards supplied to all the states by the National Institute of Standards and Technology assure uniformity throughout the country.

THE METRIC SYSTEM

The need for a single worldwide coordinated measurement system was recognized over 300 years ago. Gabriel Mouton, Vicar of St. Paul's Church in Lyons and an astronomer, proposed in 1670 a comprehensive decimal measurement system based on the length of one minute of arc of a great circle of the Earth. Mouton also proposed the swing length of a pendulum with a frequency of one beat per second as the unit of length. A pendulum with this beat would have been fairly easily reproducible, thus facilitating the widespread distribution of uniform standards. Other proposals were made, but more than a century elapsed before any action was taken.

In 1790, in the midst of the French Revolution, the National Assembly of France requested the French Academy of Sciences to "deduce an invariable standard for all the measures and all the weights." The Commission appointed by the Academy created a system that was, at once, simple and scientific. The unit of length was to be a portion of the Earth's circumference. Measures for capacity (volume) and mass were to be derived from the unit of length, thus relating the basic units of the system to each other and to nature. Furthermore, larger and smaller multiples of each unit were to be created by multiplying or dividing the basic units by 10 and its powers. This feature provided a great convenience to users of the system, by eliminating the need for such calculations as dividing by 16 (to convert ounces to pounds) or by 12 (to convert inches to feet). Similar calculations in the metric system could be performed simply by shifting the decimal point. Thus, the metric system is a "base-10" or "decimal" system.

The Commission assigned the name mètre -- meter -- to the unit of length. This name was derived from the Greek word metron, meaning "a measure." The physical standard representing the meter was to be constructed so that it would equal one ten-millionth of the distance from the North Pole to the equator along the meridian running near Dunkirk in France and Barcelona in Spain.

The initial metric unit of mass, the "gram," was defined as the mass of one cubic centimeter (a cube that is 0.01 meter on each side) of water at its temperature of maximum density. The cubic decimeter (a cube 0.1 meter on each side) was chosen as the unit for capacity. The fluid volume measurement for the cubic decimeter was given the name "liter."

Although the metric system was not accepted with enthusiasm at first, adoption by other nations occurred steadily after France made its use compulsory in 1840. The standardized structure and decimal features of the metric system made it well suited for scientific and engineering work. Consequently, it is not surprising that the rapid spread of the system coincided with an age of rapid technological development. In the United States, by Act of Congress in 1866, it became "lawful throughout the United States of America to employ the weights and measures of the metric system in all contracts, dealings or court proceedings."

By the late 1860s, even better metric standards were needed to keep pace with scientific advances. In 1875, an international agreement, known as the Meter Convention, set up well-defined metric standards for length and mass and established permanent mechanisms to recommend and adopt further refinements in the metric system. This agreement, commonly called the "Treaty of the Meter" in the United States, was signed by 17 countries, including the United States. As a result of the Treaty, metric standards were constructed and distributed to each nation that ratified the Convention. Since 1893, the internationally adopted-to metric standards have served as the fundamental measurement standards of the United States.

By 1900 a total of 35 nations -- including the major nations of continental Europe and most of South America -- had officially accepted the metric system.

In 1960, the General Conference on Weights and Measures, the diplomatic organization made up of the signatory nations to the Meter Convention, adopted an extensive revision and simplification of the system. Seven units -- the meter (for length), the kilogram (for mass), the second (for time), the ampere (for electric current), the kelvin (for thermodynamic temperature), the mole (for amount of substance), and the candela (for luminous intensity) -- were established as the base units for the system. The name Système International d'Unités (International System of Units), with the international abbreviation SI, was adopted for this modern metric system.

In 1971, the U.S. Secretary of Commerce, in transmitting to Congress the results of a 3-year study authorized by the Metric Study Act of 1968, recommended that the U.S. change to predominant use of the metric system through a coordinated 10-year national program. The Congress responded by enacting the Metric Conversion Act of 1975, calling for voluntary conversion. Amendments to the Act in 1988 designated the metric system as the "preferred system of weights and measures for United States trade and commerce."

Measurement science continues to develop more precise and easily reproducible ways of defining measurement units. The working organizations of the General Conference on Weights and Measures coordinate the exchange of information about the use and refinement of the metric system and make recommendations concerning improvements in the system and its related standards. The General Conference meets periodically to ratify improvements. Additions and improvements to SI were made by the General Conference in 1964, 1967-1968, 1971, 1975, 1979, 1983, 1991, and 1995.

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Technology Administration
National Institute of Standards and Technology